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LOPMENT/DEPLOYMENT INVESTIGATION
OF
CABINTAXI/CABINLIFT SYSTEM

CABINENTAXI/CABINENLIFT
UNTERSUCHUNG VON
TECHNOLOGIE, ENTWICKLUNG UND BETRIEB

Jointly Prepared by

Gemeinschaftlich erstellt von

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FINAL REPORT

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16. Abstract

This report presents the results of an investigation of the Cabintaxi/Cabinlift automated guideway transit (AGT) systems under development in the Federal Republic of Germany. These systems have not been conceived and designed for a particular transportation need at a specific site, but as a modular set of "building blocks" which can be configured into specific systems to suit a variety of applications. The systems are still evolving; most of the individual components have reached a high level of maturity, while the technical development of others has just begun. A Cabintaxi/Cabinlift system has not been deployed for use by the general public except for a simple, single-vehicle shuttle system at a hospital in Ziegenhain, Germany. The present technology is the result of an iterative design process which began in 1969 and has been greatly aided by the use of a large and sophisticated test facility in Hagen, Germany since 1973.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	squere miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
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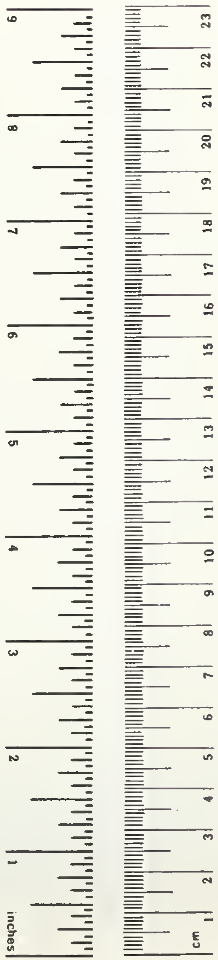

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
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cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
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m^3	cubic meters	1.3	cubic yards	yd^3
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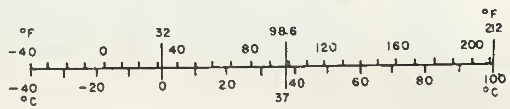

PREFACE

This report documents an investigation of the Cabintaxi/Cabinlift Automated Guideway Transit (AGT) systems under development in the Federal Republic of Germany. The study was carried out by The Department of Transportation's (DOT) Transportation Systems Center (TSC) and the Studiengesellschaft Nahverkehr mbH (SNV), under a bilateral agreement between the U.S. Department of Transportation and the German Federal Ministry of Research and Technology (MORT). The study was sponsored in Germany by MORT and in the United States by DOT's Urban Mass Transportation Administration's (UMTA) Office of Socio-Economic and Special Projects of the Office of Technology Development and Deployment.

The study consisted of a review of technical reports and papers; on-site visits to the test facility in Hagen, Germany and the single-vehicle shuttle system in Ziegenhain, Germany; and interviews with technical and managerial personnel from the developers, Messerschmidt-Bölkow-Blohm GmbH (MBB) and DEMAG Fördertechnik (DEMAG). The cooperation received from the developers throughout this study has been excellent. The material in this report has been reviewed by the manufacturers. The report is available in both German and English.

The authors wish to acknowledge the special efforts of Hermann Zemlin of SNV, and Frank Tung and Nancy Ratcliffe of TSC in the preparation of the English version of this report for publication, as well as the technical contributions of Messrs. Ronald Kangas and George Anagnostopoulis (also of TSC) in the early phases of this study. Many of the photographs in this report were taken by Mr. Anagnostopoulis.

Major German contributions to this report have been made by Raimund Angstmann, Jobst Brüggemann, Günther Burkart, Hella Häussler, Horst-Walter Hilganfeld, Werner Horsmann, Axel von Knobloch, and Frank Weyerstall. Review and comments have also been provided by Alfred Wild, IABG.

The authors wish to thank George Pastor of UMTA's Office of Technology Development and Deployment and Rainer Göetz of the German Federal Ministry of Research and Technology for the special interest they have taken in this study.

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1. EXECUTIVE SUMMARY

1.1 BACKGROUND & INTRODUCTION

This report presents the results of an investigation of the Cabintaxi/Cabinlift automated guideway transit (AGT) systems under development in The Federal Republic of Germany. The study was conducted under a bilateral agreement between the U.S. Department of Transportation (DOT) and the Germany Federal Ministry of Research and Technology (MORT). It was carried out jointly by DOT's Transportation Systems Center (TSC) and the Studiengesellschaft Nahverkehr mbH (SNV). The Cabintaxi/Cabinlift investigation is sponsored in Germany by MORT and in the United States by DOT's Urban Mass Transportation Administration (UMTA). In the United States, this is one of several assessments of AGT systems, both domestic and foreign, being conducted by the Office of Socio-Economic and Special Projects of UMTA's Office of Technology Development and Deployment. The purposes of these assessments are to:

1) Gather and exchange information on Automated Guideway Technology to better understand the state of technological advancement and to obtain synergistic improvements for future development.
2) Review problems and solutions encountered during the design, development, implementation, and operation of AGT systems in order to improve the process based on experience.
3) Obtain information on engineering, economic, operational performance, and public response which can be used in planning future AGT systems.
4) Provide urban planners with information which will enable them to determine the applicability of AGT systems to their specific transportation problems.

The Cabintaxi/Cabinlift systems differ from the other AGT systems currently being studied under UMTA's Assessment Program in two significant ways:

1) These systems have not been conceived and designed for a particular transportation need at a specific site. The Cabintaxi/Cabinlift concept is one of modularity: a set of components and operational modes which are being developed as building blocks to suit a variety of applications.

2) The systems are still evolving; most of the individual components have reached a high level of maturity, while the technical development of others is just beginning. A Cabintaxi/Cabinlift system has not yet been deployed for use by the general public except for a simple, single-vehicle shuttle system in Ziegenhain, Germany.

The latter point reflects the German approach to fielding of new systems, which is characterized by an extensive and lengthy development period to refine the design of individual components in order to reduce the risks associated with implementation. The present Cabintaxi/Cabinlift technology is the result of an iterative design process which began in 1969 and has been greatly aided by the use of a large and sophisticated test facility in Hagen since 1973.

This report focuses on a description of the technological concept; the status of the systems (and major subsystems) relative to deployment; experience gained in design refinement and reliability through realistic testing; theoretical analyses; and feasibility studies. UMTA's other assessment reports focus, in addition, on "lessons learned" during system deployment, performance experience in carrying passengers and public response; these types of information relative to Cabintaxi/Cabinlift must await future deployments such as those currently under consideration for Hamburg, Marl, and other cities.

1.2 SYSTEM DESCRIPTION

The system presently boasts three types of vehicles: a three-passenger vehicle (KK3), a twelve passenger vehicle (KK12), both accommodating seated passengers only, and a Cabinlift vehicle, which is a slightly larger cargo or passenger vehicle whose height will accommodate standees. The three basic vehicle types of different physical dimensions are associated with particular operational strategies, and thus a specific class of applications as shown in the table in page 1-3.

Larger vehicles are under development. A fourth vehicle, similar to the KK12 has been developed as a rescue and maintenance vehicle. A less sophisticated rescue and maintenance "cage" is also available.

Vehicle propulsion is accomplished with linear induction motors (LIM). Operational speed is presently 10 m/sec for the KK3 and KK12 vehicles and 5 to 8 m/sec for the Cabinlift vehicles. Development is underway to increase

	Physical Dimensions			Operational Strategies
	Length (m)	Width (m)	Height (m)	
KK3	2.0	1.7	1.6	Destination Discretionary (Personal Rapid Transit (PRT) - Demand mode)
KK12	4.8	1.7	1.6	Line Transport (Scheduled mode) or mixed Scheduled and Demand mode
Cabinlift	3.94	2.44	2.40	Line Transport (Scheduled mode) or mixed Scheduled and Demand mode

the operational speed to 15 m/sec. Linear induction braking (LIB) is supplemented with wheel drum brakes at low speeds and for reinforced emergency braking. An on-board battery provides emergency power for these subsystems.

Vehicle switching is mechanically passive on the guideway and accomplished by fixed form guides which engage a set of steering wheels on either side of the vehicle. Special guide rails are fixed to the track at branching points and the switch wheels are set right or left by the vehicle in response to switching commands.

The narrow guideway typically elevated, can be constructed to carry two-way traffic on the same beam utilizing both suspended and supported vehicles, or one-way traffic utilizing either suspended or supported vehicles. The guideway is usually of steel construction; but may be fabricated as a steel/concrete composite. Several types of guideway supports have been developed: cantilevered arm, T-form, mushroom, and pylon. Two other support forms, goal post and portal, could be used with the system. The supporting columns can be either concrete or steel. System networks are formed by linked, closed guideway loops, since travel is one-way on a particular level and "crossings" are not feasible.

Stations may be on-line or off-line, and dual level, depending on the operational strategy employed in a given application. They are also modular and prefabricated.

The Cabintaxi/Cabinlift system is automated through a hierachical control system, having three independent levels: 1) vehicle headway and speed regulation, and merge control; 2) station control including vehicle destination coding, switch direction selection, and traffic flow counting; and 3) network control for dispatching, monitoring and traffic flow management. The first level of control is critical to system safety and general operational capability. Levels two and three are important to passenger processing, system availability, and optimal operation. Failures in either level two or three will degrade but not halt system operation.

The longitudinal control system is asynchronous, using a vehicle follower concept, and permits 1.4 second headway and vehicle platooning. A particularly innovative technique has been applied to the control of merging streams of vehicles which minimizes the perturbation to the speed of successive vehicles in merging platoons, thus improving on the ability to stabilize the system in normal operation.

1.3 DEVELOPMENT STATUS

An unusually extensive test facility has been constructed in Hagen, Germany. The facility consists of both supported and suspended vehicle guideway sections, merging and demerging switches, various types of guideway supporting elements, and at the moment three stations, a maintenance facility, nine KK3 vehicles, one KK12 vehicle, a maintenance and recovery vehicle, a maintenance cage, a power collector wear-test track, and the basic elements of the control system, with the exception of the level-three network control, which is rudimentary at this time. This facility has been the source of most of the operation, subsystem, and component test experience to-date, and has permitted refinement of basic design through a repeated sequence of test, modification, redesign and retest. In this manner, components used for a specific application go through a process which should minimize the developmental risks associated with new system implementation.

A single-vehicle shuttle system utilizing the Cabinlift-type vehicle has been installed as a single length of suspended vehicle guideway between two buildings of a hospital complex in Ziegenhain, Germany. This system utilizes selected portions of the overall system technology modified to fit the special application. The system was constructed utilizing prefabrication techniques and components which had gone through the developmental process at the test facility. As a result, the 578 meter long guideway was installed in three months. The total system cost in 1976 of approximately DM 2.2 million ($880,000) was less than 10% over the contracted price of DM 2.056 million ($822,400) in 1975, and only three months of pre-operational on-site testing was required. The system has been operational since July of 1976 and has experienced a 98.7% availablity. The Ziegenhain Cabinlift system does not require a central control system, a multi-vehicle headway control system, or a mechanism for switching. It has provided the opportunity to gain operational experience in a real-world application, and represented the first step in defining certification procedures and safety standards for automated transportation systems in Germany. The Ziegenhain system was certified as a horizontal elevator with some additional considerations.

Computer simulation is being used extensively in the development of the Cabintaxi/Cabinlift systems. Initially, simulation was employed in developing the merge control scheme in conjunction with the vehicle interval measuring system. More recently, it is being used as a planning aid to develop optimum network control algorithms and software for specific application feasibility studies, to assist in determination of appropriate guideway geometry for safety and ride comfort factors, and to estimate capital and operational costs of specific systems.

1.4 FINDINGS AND CONCLUSIONS

The major findings and conclusions of this investigation may be summarized as follows:

1.4.1 System Concept and Operation

- The design philosophy for the Cabintaxi/Cabinlift systems, to fabricate a set of AGT modules or "building blocks," has resulted in a system concept with broad flexibility for application.

- The hierarchical approach to control system implementation will permit safe system operation, albeit with degraded performance, in the event of loss of the central control computer or malfunctions at the station level, thus possibly improving system availability.

- The stations and the guideways are aesthetically pleasing which should increase the probability of community acceptability. The narrow guideway represents an extremely small cross section for two way traffic.

- The innovative design of the switches strives for the merging of platoons of vehicles with minimal propagation of speed reduction in the platoons, thus further improving the link capacity potential.

- The vehicles are compact, light weight, and generally attractive. The ratio of the maximum loading to empty vehicle weight is 33% for the KK3 vehicle and 50% for the KK12 vehicle.

- The use of linear induction motors for the systems offers significant advantages over friction drives relative to grade, noise, wear, and all weather operations. In addition, recovery of disabled vehicles by pushing or pulling is facilitated by the minimal friction characteristics of the LIM. However, LIMs require stringent alignment of reaction rails and possible greater energy use due to inherently less efficient motors.

1.4.2 Passenger Related Aspects

- The manufacturers have addressed themselves to fire safety in a number of ways, i.e., fire retardant material and insulation, rescue vehicles, etc. A pushbutton is also provided in the cabin which when energized will instruct the vehicle to stop at the next nearest station. In most planning studies to date, the distance between stations is from 400 to 700 meters.

- The system safety philosophy includes door interlocks which cannot be opened on the guideway between stations except by personnel using a rescue vehicle. Therefore, it is not possible for passengers to exit the vehicle on the guideway in the event of emergency or fire without external help.

- Reasonable consideration has been given to handicapped and elderly persons in the system design, e.g., wide doors, leveling devices in the Cabinlift system, elevators in the stations, etc. The current design however, requires the negotiation of a 15 cm (6 inch) step in order to board a KK3 and KK12 vehicle to make entry into the compact vehicles easier for the normal passenger. This could prove to be a difficult maneuver for wheelchairs without assistance.
- The current design of the stations permits access to the guideway on supported vehicle systems. Since there is no provision for automatic detection of people or objects on the guideway, this situation could prove hazardous if restricting doors or other solutions are not provided.
- The present heating and ventilation system in the vehicle, developed for the relatively mild middle European climate, may not be adequate for the more extreme climatic variations in the United States.
- Barrierless fare collection is employed in the Cabintaxi/Cabinlift systems, as in the conventional transit systems in Germany. While this mode of operation may be acceptable in the KK3 type of systems, which combines small cabins and magnetic-card-controlled specific destination selection, the barrierless fare collection approach may not be appropriate for the United States market with KK12 or other large vehicles. Therefore, a barrier-fare-collection system should be considered for the larger vehicle Cabintaxi/Cabinlift systems for use in the U.S.A.

1.4.3 System Development and Deployment

- The aspects of system design which make the system "fail-safe" are currently being developed. These features must undergo rigorous test and evaluation before the system can be considered eligible for public deployment, if more than one vehicle is required in the system.
- The availability of proven components, as well as modular and prefabricated guideways and stations suggest potential savings in construction time, and reduced developmental risk and costs.

- The fact that there has not yet been a deployment of the system serving the general public in a multi-vehicle complex network configuration must leave to future experience the question of achieved performance versus expected and simulated performance in several areas: service availability, schedule maintenance, network management efficiency, failure recovery management, maintenance strategies, computer network operation and reliability, aspects of public acceptance, and the ability to determine and meet realistic system residual development and deployment schedules in the face of political, social, and economic pressures. A demonstration system is currently in the planning stages for post 1980.
- The extensive use of computer simulation by the manufacturer has been an important and beneficial aspect of the development program, and will play a key role in effective system planning.
- The manufacturers have been and are vigorously pursuing optimization of the crashworthiness of their vehicles, even though all AGT control systems must be designed for "fail-safe" operation.
- System certification procedures and development of an appropriate safety philosophy (or standards) for new automated transportation systems are currently under consideration in West Germany, and should be investigated in the United States.
- Planning guidelines for the implementation of elevated guideway systems in urban areas should be developed to assist urban planners considering automated transportation systems.
- The relatively short construction time and small amount of testing required for operational readiness of the Cabinlift system at Ziegenhain hospital was the result of having fully developed and tested the system components and installation techniques at the Hagen test facility.
- The system as installed at the Ziegenhain Hospital is considerate of the handicapped, aesthetically and architecturally pleasing, very quiet, has a relatively smooth ride and is land-use and energy efficient. Maintenance procedures are relatively simple and the system, thus far, has been quite reliable.

- The development philosophy adopted by the manufacturers can be characterized as an intensive, well ordered and directed effort aimed at proving the feasibility of basic design assumptions. Considerable attention has been paid to "front-end" engineering and design tasks with impressive results during test and evaluation. This can be a significant factor in meeting both deployment schedules and system performance and reliability objectives.

2. SCOPE OF REPORT

The approach taken for this study, and consequently this report, differs from that of the other UMTA assessment activities currently underway in that the cabintaxi/cabinlift systems have not been deployed for use by the general public, with the exception of the single vehicle shuttle (horizontal elevator) installed between two hospital buildings in Ziegenhain, Germany (see Appendix A). Therefore, operational performance information, implementation, and public operational experience are limited primarily to test facility experience and data derived theoretically or via simulation.

In addition, Cabintaxi/Cabinlift is a technological concept designed for versatile application to a cross section of transportation needs, rather than a specific system designed for a particular application at a predetermined site.

This report, therefore, describes the overall design and development philosophy adopted by the manufacturers, the existing and planned technology and system concepts, the development experience to date, and the costs and performance levels achieved through several years of design refinement and test track experience.

Chapter 3 sets forth the purpose of this study, briefly explains how the Cabintaxi/Cabinlift project came into being, outlines the project organization, the division of responsibilities between and the developers, Fördertechnik (DEMAG) and Messerschmidtt-Bölkow-Blohm, GmbH (MBB), and elaborates on the overall project objectives.

Chapter 4 provides an overview of the system concept, operational modes, and major subsystems as well as a more detailed technological description of the significant system elements, such as the control system concept and implementation, guideway types and network layout considerations, switching system, and various vehicle types along with their propulsion and braking system traits.

Overall system characteristics are presented in Sections 4.7 through 4.14. These include the philosophy of fare collection systems; operational support factors, such as energy supply and maintenance facilities; system safety features; reliability and availability philosophy; test track data; theoretical system performance; network planning and current simulation aids; and adverse weather operation.

Chapter 5 discusses the operational deployability status of the systems as of October, 1976, and includes updated information provided by the manufacturers as of April, 1977. This discussion highlights plans for the Bremen Hospital system, and developmental status of several pertinent aspects of the automated control systems. A history of the extensive test program is given in Section 5.5.

Chapter 6 addresses several of the key human factors aspects of the system including noise, ride quality, public acceptance issues, considerations relative to using the system, fire safety, vehicle crashworthiness, personal security factors, and provisions for the elderly or handicapped.

Chapter 7 deals with component costs of system installation and operation based on developmental experience to date, comparable cost expenditures for other forms of transportation, and mathematical cost models for specific feasibility studies.

Chapter 8 deals with the phased system development and the philosophy of introducing the system into the transportation market in an incremental fashion.

Chapter 9 summarizes the findings and conclusions developed by TSC and SNV as a result of this particular system investigation, some of which are generalized for application to other new transportation systems.

Appendix A is a separate study of the Cabinlift shuttle system installed at the hospital complex in Ziegenhain, Germany. Features of that system, which are specific to the hospital environment, are discussed and operational experience is presented.

3. INTRODUCTION

3.1 REASON FOR STUDY

In the spring of 1976, plans were finalized for a joint U.S./German study of the Cabintaxi/Cabinlift Automated Guideway Transit (AGT) technology under development in the Federal Republic of Germany. This project was initiated under an agreement between the German Federal Ministry of Research and Technology (MORT) and the United States Department of Transportation. The agreement calls for cooperation in the assessment of AGT technologies in order to guide further research, development, demonstration, and deployment decisions relative to AGT.

The development of the Cabintaxi/Cabinlift concept is proceeding under the aegis of the German Federal Ministry of Research and Technology through a joint venture arrangement between the German firms DEMAG Fördertechnik (DEMAG), and Messerschmitt-Bölkow-Blohm, GmbH (MBB).

The study documented in this report was carried out during the fall of 1976 and Spring of 1977 by the Transportation Systems Center (TSC) under sponsorship of the Urban Mass Transportation Administration (UMTA), and the Studiengesellschaft Nahverkehr mbH (SNV) under contract to the German Ministry of Research and Technology, with the cooperation and assistance of both DEMAG and MBB.

The Cabintaxi/Cabinlift investigation is one of several assessments, both domestic and foreign, of AGT systems being conducted by UMTA's Office of Socio-Economic Research and Special Projects.

The purpose of these assessments are to:

a) Gather and exchange information on Automated Guideway Technology, to better understand the state of technological advancement, and to obtain synergistic improvements for future development.

b) Review problems and solutions encountered during the design, development, implementation, and operation of AGT systems in order to improve the process based on experience.

c) Obtain information on engineering, economic, operational performance, and public response which can be used in planning future AGT systems.

d) Provide urban planners with information which will enable them to determine the applicability of AGT systems to their specific transportation problems.

This particular assessment has also provided the opportunity for international cooperation and technical exchange.

3.2 SYSTEM BACKGROUND

The serious problems of urban transport in the population centers of the Federal Republic of Germany have come increasingly to the forefront since the end of the sixties. The discrepancy between the available street area and the number of motor vehicles continues to grow in spite of intensive efforts on the part of the cities. The problem of street traffic affects not only individual transport but also 80% of the public transport systems.

This critical urban transport situation led, in 1969, to independent studies by engineering teams from both the DEMAG and MBB. These studies revealed the following situation with regard to the state of public transport systems in the Federal Republic of Germany.

- Barely 20% of the public transportation systems have dedicated traffic ways.
- The use of available seating in public transport systems is, on the average, 20% or lower.
- Public transport is used on only 20% of the trips made within the city, although 50% of all automobile trips in the city are connected with work. (That is, trips which should be within the domain of the public transport system).
- Over 70% of the operational costs of the public transport system are for personnel and staff, and therefore, the economy of urban transport system operation is determined to a large extent by those costs.

On the basis of these findings, the urban transport system of the future should meet the following requirements.

- Reduction of the personnel costs: meaning automation in so far as it is technically and economically feasible.
- Dedicated traffic areas for public transport in order to remove the problems and operational concerns of the individual transport sector from public transport.
- Operational procedures and scheduling which are attractive to the passenger and allow better usage of available space in the vehicle.

The first preliminary analytical studies for unconventional urban transport systems were published in the Spring of 1970. These studies were carried out based on traffic analyses provided by local or state authorities. The fundamental concept of the small cabin system with dedicated guideways and automated operation for discretionary (on demand) use was proposed.

The development costs of such a technically difficult urban transport system were too high to be carried by a single industry. The DEMAG and MBB companies, on the basis of preliminary studies conducted independently from each other submitted separate proposals to the Ministry for Research and Technology (MORT). Both firms in their proposals recommended the development of a small cabin system. Many components of the systems recommended by these two firms were identical. Because of the substantial agreement with regard to the system concept, the MORT recommended that the two firms work together toward the goal of developing a general small Cabinrail system.

The various types of research and production programs of the two industrial firms were complementary in product and expertise. In 1971 the two firms formed the "Cabintaxi Work Group," whereby the division of responsibility for the various system aspects were made according to the individual firms' development and production experience. The DEMAG firm concentrated its efforts in the area of mechanical construction, while MBB worked in the area of automation component development.

A subsequently presented planning study for the cities of Freiburg (May 1971) and Hagen formed the basis of the group's new joint proposal to the MORT.

This study focused on critical concerns with respect to traffic, integration into the city structure, and the economics of a suitable Cabintaxi system.

After basic evaluation of the conveyance proposals by the MORT and the appropriate advisory boards, the conclusion was reached that the system concept presented offered a promising, attractive, and unconventional alternative to the present day public transport systems. In addition, the technical components of this system, being modular, could lead to other uses for modified, unconventional urban transport systems confined to a track. For example, the development and research results of the small cabin system lent themselves to the development of the large cabin, which in suitable form could be converted to a cargo vehicle and round out the product family. In this way a broad application spectrum in the traffic sector could be covered.

Due to these considerations, the MORT started as of January 1, 1972 to carry 80% of the development costs of the project; 20% of the cost is financed by the "Cabintaxi Work Group." Permission for the go-ahead on subsequent stages of development were to be made after 2 to 3 years, after which time reviews would be made of progress in terms of the results and goals reached up to that time, and the resultant chances for realization of the project would be re-evaluated.

3.3 PROJECT ORGANIZATION

The MORT recommendation that the DEMAG and MBB industrial firms closely cooperate on the development of the urban transport Cabintaxi system led to the establishment of the "Cabintaxi Work Group." Each firm set up an interdisciplinary project team for addressing the common research tasks. A specially equipped department would be assigned when necessary to a special problem area. Furthermore, qualified specialist firms could be subcontracted if required for individual critical problems. The Cabintaxi Work Group was to be managed by a common project committee. The project leaders of the project teams from the DEMAG and MBB firms were equally ranked members of the project committee.

The specific production program backgrounds of the two partner firms made possible a clear division of project assignment within the project according to the know-how of each firm. The Cabintaxi urban transport project was divided into the following 9 areas:

- System analysis
- Planning
- Stations
- Guideways
- Operational support
- Backup vehicles
- Vehicle regulation
- Network control
- Operational software

Each of the subsystems was divided again into ten main components. The project structure of the Cabintaxi development, as well as the assignment of projects within the DEMAG-MBB research group, is represented in Figure 3-1.

The Government involvement in the project through the MORT is to assure that the public resources available for such a project are used in an appropriate manner. This is only possible through constant monitoring of the progress of the project with regard to technical time and cost factors; but the MORT has limited personnel resources. Therefore, the Industrieanlagen-Belriebsgesellschaft GmbH (IABG) has been contracted to carry out these tasks.

The DEMAG and MBB developmental firms have the responsibility each quarter of submitting a detailed progress report to the MORT and the IABG (project monitor). The IABG reviews these reports and conducts personal interviews and discussions with the development firms to assess the progress of the work. The IABG supplies an informed commentary to the quarterly reports from the firms, supplemented and rounded out as necessary by suggestions for possible solutions to specific problems, and thus provides the MORT with important information on which it can base its decisions.

Because of the long term development necessary and the high development risks, the MORT only provides public resources for the Cabintaxi project over a 2 to 3 year interval. Upon expiration of this term, an extension proposal can be presented by the Cabintaxi Work Group (ARGE). This proposal would be reviewed by the MORT, the IABG, and an advisory board from the public transport sector consisting of independent experts to assess technical, operational, and

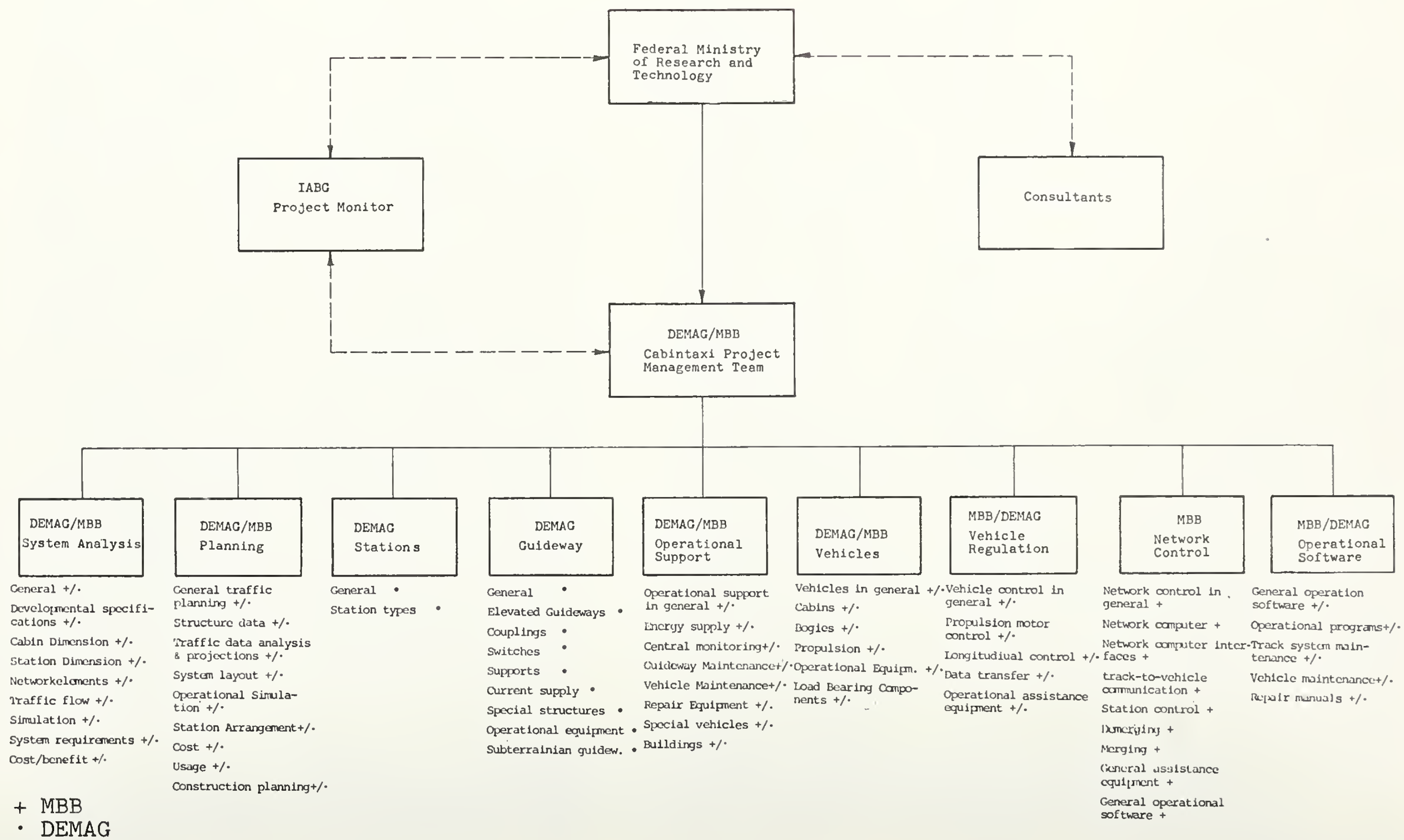


Figure 3-1. Block Diagram of the Project Structure of the Cabintaxi System

transport questions. The MORT, supported by these independent experts and neutral advisory boards, makes its decisions with regard to continued involvement in the Cabintaxi research project.

3.4 ESTABLISHMENT OF OBJECTIVES

In establishing the performance objectives for a new transport system, the requirements and needs of three interest groups must be satisfied, i.e., the user, the operator, and the environment. The system must also be capable of handling increasing traffic requirements in the coming decades. Expectations of the interest groups are as follows:

User	Operator	Environment
quick	sufficient performance	low environmental stress from noise & pollution
comfortable	low operational cost	
safe	dedicated traffic ways	high performance with low space requirements
economical	high reliability	
	possible integration with existing transport systems	possible integration into city architecture
		adaptability of system to city structural changes

These requirements of the new system must be met with close attention to economics, as well as the thoughtful and appropriate application of technological resources.

The transport system recommended by the DEMAG and MBB working groups to meet these objectives is the Cabintaxi/Cabinlift system, having both area and axial applications. The Cabintaxi/Cabinlift systems are to a large extent based on the same technology.

The features these systems have in common are as follows:

- Vehicles which are comfortable, having seats and sufficient room for luggage.

- Travel on a dedicated guideway which is separated from street traffic.
- Separate track levels for supported and suspended vehicles on a normally elevated, single guideway.
- Electrically driven vehicles, offering freedom from exhaust and noise.
- Fully automated driverless operation.

The features of systems with small cabins are:

- Specific destination discretionary (demand mode) direct transport between departure point and destination without interim stops or transfers.
- Continuous availability of the small vehicles at stations which have off-line tracks.
- Travel speeds of at least 30 km/h and up to 50 km/h.

The features of systems with large cabins are:

- Good integration with existing mass transport, due to better capacity to handle periodic high loading and to form vehicle trains.
- High link capacity with fewer vehicles.
- Simplified automation in small networks is possible.

Components developed for the large vehicle system have had their first practical trails in the Ziegenhain Cabinlift system. This system is a horizontal elevator connecting two parts of the hospital in Ziegenhain, Germany (see Appendix A). The system is equipped with a single 12-place cabin for the transport of personnel and cargo.

4. DESCRIPTION OF TECHNOLOGICAL AND DESIGN CONCEPTS

The Cabintaxi/Cabinlift system refers to a transport system which is constructed in a modular fashion from components which are very similar in principle. Development of the system is not yet finished; various components have reached different stages of development. A large part of the technology of the system, however, has been developed on a large test facility and a portion of it applied as a special system: the Ziegenhain Cabinlift. "Cabinlift" is a name given by the manufacturer to a system designed for general application. The Cabinlift facility at the Ziegenhain Hospital near Kassel, which is operated as a horizontal elevator facility, is discussed as a special system in Appendix A to this study.

The discussion in this chapter, then, will cover technology which has been achieved, as well as planned development objectives, without necessarily distinguishing between them. (The status of development achieved thus far relative to system deployment will be covered in Chapter 5). Results of theoretical research as a part of the Cabintaxi/Cabinlift concept will also be presented in this chapter.

4.1 GENERAL SYSTEM OVERVIEW

The Cabintaxi/Cabinlift system is designed as a fully automated public transport system which is confined to a guideway. All system procedures and vehicle movements are carried out and controlled by a hierarchically structured electronic control system. The capability for both supported and suspended cabins permitting operation in opposite directions on a single guideway is a special design characteristic. (It is also possible to have guideways dedicated to either supported or suspended traffic.)

Several different cabin systems applied to various urban transport tasks are planned, using to a large extent similar technological concepts. The individual Cabinrail versions will be differentiated by technical modifications, and especially by differences in their operational concepts.

4.1.1 Cabintaxi and Cabinlift Systems

The development of the Cabintaxi/Cabinlift technology has as an objective the realization of several transport systems which are well suited to assume various roles in the overall transport sector.

Fundamentally, the cabin systems are designated according to vehicle size, the accompanying type of operation, and the area of application. These designations fall into three groups: namely Cabintaxi KK3, Cabintaxi KK12, and Cabinlift (Figure 4-1).

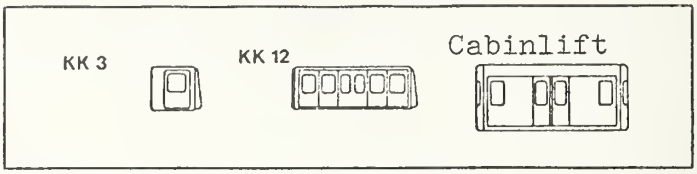


Figure 4-1. Cabinrail System

The applications area of such a system would tend to service intercity routes.

Definitions of operational strategies are according to [1]:

Discretionary Operation: (demand mode)

The vehicles travel to a specific destination anywhere in the entire network; their operation and control is in response to an actual request. (This is the original concept for the Cabinrail system.)

Normal Scheduled Route Travel: (line operation)

The vehicles travel according to a schedule on fixed routes; their operation is determined by the schedule and they do not respond to special requests. (Normal operation is a conventional transport system.)

Scheduled Route Operation with Discretionary Stops:

The vehicles travel on a fixed line, but stop at a station only when a passenger wishes to board or leave the vehicle. Otherwise, the vehicles travel at the highest possible speed. The number of cabins in operation on the

line at a given time is regulated by the line operation plan and is independent of actual individual requests or needs.

Cabintaxi KK3 (vehicle with 3 seats)

The operational strategy for the Cabintaxi KK3 system is exclusively for specific destination, discretionary travel (demand mode, non-stop to destination travel). Possible application areas are:

- A total transport system for medium sized cities
- The servicing of specific districts and high density zones in population centers, for example, service to an extended pedestrian zone with parking facilities and to shopping centers.
- A feeder line and distribution line for conventional rail systems in different areas of a population center.

Cabintaxi KK12 (vehicle with 12 seats)

Aside from normal scheduled operation, specialized discretionary strategies are possible to some extent with the Cabintaxi KK12 system (for example, scheduled operation with discretionary stops), as well as specific destination discretionary operation. The network configuration must be chosen in consideration of the primary transport task (scheduled operation), and therefore, need not be as extensive over a given area as would be required for the discretionary specific destination transport system.

Cabinlifts: (vehicles to carry from 12 to 50 passengers either seated or standing)

In the Cabinlift form of operation the cabin is controlled according to the schedule and guided to various destinations. Descretionary travel could be superimposed.

Cabinlits are especially suited to "internal" transport applications in which a regular exchange of cargo and personnel takes place between individual buildings: for example in factories, hospital facilities, airports, and at expositions or fairs.

The size of vehicles, the configuration of the track network, and whether the stations are to be "on-line" or "off-line" type, are determined by the specific application and operational strategy of the system. If a track network is to be constructed especially for specific destination discretionary

use, then all of the stations must be "off-line." For scheduled, controlled route operation, "on-line" stops could be constructed along sections of through track.

Another important difference between Cabintaxi systems KK3/KK12 and Cabinlifts is the fact that the Cabinlift has places for standing passengers. The dynamic limits of operation (jerk, acceleration, braking, etc.) are more restrictive for standing passenger systems than those for the comparable Cabintaxi systems equipped exclusively with passenger seats.

4.1.2 Test Facility and the Ziegenhain Cabinlift

The test facility near Hagen consists, for the most part, of supported and suspended vehicle track constructed in a loop for the KK3 and KK12 Cabintaxi. It is primarily constructed as a double rail on a single guideway beam (Figure 4-2).

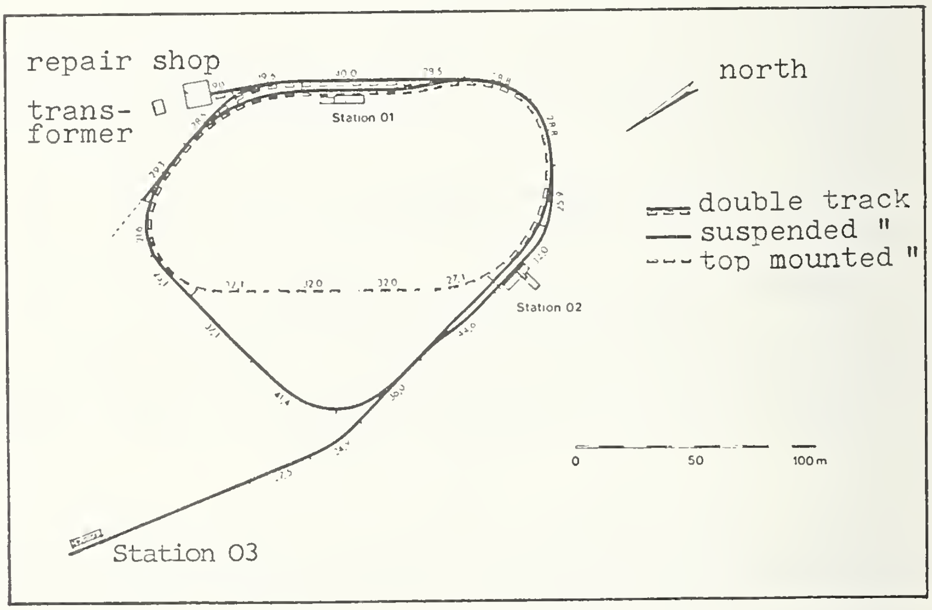


Figure 4-2. Test Facility Hagen

The test facility guideway consists of 560 m of supported vehicle track and 901 m of suspended vehicle track. The minimum turn radius is 30 m (bank of up to 5°) with an incline of 15%. It contains merging and demerging switches. This facility has available all of the major guideway components. At the present time nine KK3 Cabintaxis, one KK12 cabin, and a maintenance and/or recovery vehicle are in test operation. In addition to three stations, the facility is equipped with a maintenance shop.

The basic elements of the control system are available at the test facility; they will, to some extent, require further development. They include the headway assurance system, the control for the merge and demerge switches, and station control which is equipped with mechanisms for destination coding by means of push buttons or by means of magnetic travel tickets. The automation elements at the test facility do not yet contain a fail-safe monitor, which would make the system redundancy secure.

The Ziegenhain Cabinlift has been in practical operation since July 1976. The facility consists of approximately 600 m of suspended vehicle guideway which connects two stations integrated into two hospital buildings. Aside from the single vehicle operating in the shuttle mode (back and forth), a service vehicle is available. The control system is of the lift control (elevator) type. (See Appendix A.)

4.1.3 System Technology and Operation

In this section the overall technology and operational concepts of the Cabintaxi/Cabinlift systems are presented without going into detail on the present state of development. A summary of important system characteristics is contained in Section 4.1.4.

System Operation

The Cabintaxi operation, and especially that of the KK3 cabins, is of the specific destination discretionary type (demand mode). In the absence of the "lift control" feature in the system, the destination selection is carried out in connection with the purchase of the travel ticket. Automats (ticket machines), as well as a network map showing the stations, are located just outside the platform in the station for the purchasing of travel tickets and destination coding. The number of the destination station is entered by the passenger into the ticket automat using pushbuttons. After the price of the

ticket has been displayed by the automat and the correct amount of money has been deposited, the passenger obtains information concerning the correct platform to use, and a travel ticket with the destination encoded. A trip destination automat into which the travel card is inserted is located on each platform at each boarding position. This automat cancels the ticket and codes the destination station into the vehicle. The destination automats located on the platform are also used for network section cards (that is, more than one travel or ride on a card).

When the door opens the cabin is ready for operation. After pushing the start button inside the vehicle, the door closes and the vehicle departs the station. The next empty cabin advances to fill the empty space. Deboarding is possible from any docking position on the platform; however, vehicle boarding is only possible at docking positions which are equipped with destination automats.

Speed up to the operational speed of 10 m/s (in tests 15 m/s) is reached on the off-line track before the vehicle is merged into a clear track section. The cabin steers itself to the destination. At the destination station the vehicle leaves the main track, enters an off-line track, decelerates and continues slowly up to the platform.

For scheduled route operation, the travel procedure is similar to that of an automatic conventional rail operation. The passengers insert their tickets coded with a destination code or a Zone code and board a KK12, or other middle sized cabin along with other passengers.

Control System

The automatic cabin transport is controlled by a hierarchical control system, having three almost completely independent levels. These are:

- Headway and speed regulation, and control of merging into the traffic stream.
- Station control, destination coding and direction selection, traffic flow counting.
- Network control (dispatching and monitoring).

This three-level decentralized design prevents the failure of one control unit affecting the availability of the entire system. Even with total failure

of the network computer (central control) the system remains operational, although to a somewhat limited extent.

For headway control, each vehicle is equipped with a transmitter and a receiver permitting an alternating current signal to be received, or induced into a cable fastened to the guideway. Using a drive-control unit, the speed of each cabin is adjusted so that the absolute working interval between vehicles is not violated (Figure 4-3).

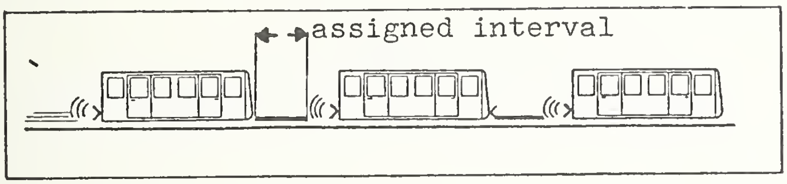


Figure 4-3. Headway Control

Signals are transmitted from a given cabin to the cabin following it on the line. This signal is damped according to the line resistance. Since the distance between the vehicles is determined by the amplitude of the signal, uniformity in the amount of damping per unit length along the line is critical. For this reason a redundant fail-safe monitor control is planned for the signal damping cable. In the case of power failure, the headway control units would be powered from on-board batteries. A "dead cabin" would be protected by the removal of the fail-safe "go-ahead" travel signal.

For the merging switches, an "automobile zipper procedure" is used. The vehicles are mirrored onto the parallel running tracks via a fixed electronic conductor in the headway measuring cable (Figure 4-4): thus, they appear as virtual vehicles whose presence influences the operation of actual vehicles in the parallel track. In this way the necessary gaps are created between vehicles before merging at the switch.

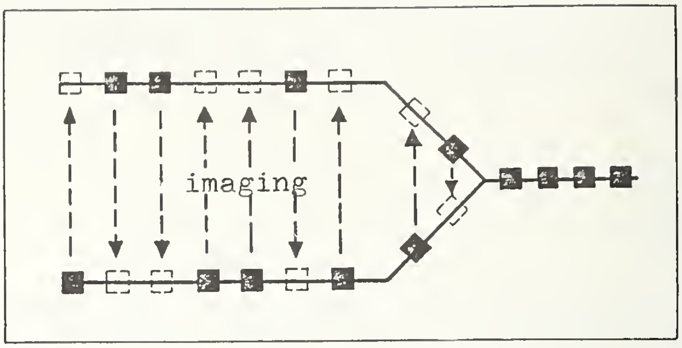


Figure 4-4. Virtual Image Range Preceding Merging Switch Point

The station computer has a large number of functions to fulfill. It receives the passenger's selected destination and orders an empty cabin or prepares one from the ready line. In addition, the computer transmits the destination address to the vehicle which stores it into its mission logic memory. Vehicles can also transfer mission logic data regarding defects or interference with operation to the station.

The station computer also regulates branching from the demerge switches. At a sufficient distance from the demerging switch, the switch control unit reads the address or line information which has been stored into the vehicle while at the station. The switching unit is supplied with a list of destination addresses of all the stations as well as a list of switching commands. These commands are carried out by the steering wheels on the vehicle. The list of switch commands can be changed at any time by the network computer if the vehicle is to be rerouted during the trip.

The network computer will regulate the system on the basis of the traffic density, track section load, and the dispostion of empty vehicles. It will

select for all origin-destination pairs the quickest route on the network. In case of problems on any given track section, the selected route can be modified at any time.

Failure of the station control elements, or those of direction control or demerging switches, or the network computer, have no influence on operational safety. Failures of these subsystems cause hindrance to the smooth flow of traffic; they cannot, however, cause an accident. In contrast, the headway control system and merge control system carry a large responsibility with regard to safety.

Vehicles

In addition to vehicles for transport of personnel (i.e., Cabintaxi KK3, KK12, and Cabinlifts of different sizes), service vehicles and Cabinlift vehicles which have been specially modified for cargo transport have been planned. The KK3 cabins, one KK12 vehicle, and a service vehicle are presently under test at the test facility in Hagen. A Cabinlift vehicle is at the present time in practical use at the Ziegenhain Hospital (see Appendix A).

The two Cabintaxi vehicles (KK3, KK12) are to a large extent similar in their behavior. They offer three or twelve seats, and have the same width and height dimensions (Figure 4-5).

Entry into the vehicle requires the negotation of a 15 cm step. It is possible, however, to load baby carriages as well as luggage.

In the 3-seat vehicle, the passengers face the direction of travel and have a view of the surrounding areas as well as the track supports through large front and side windows. Coupling of the KK3 cabins to form trains is not planned.

In the 12-seat cabin, passengers sit facing one another with a view in the direction of travel, or vice versa. It is planned that these cabins will have the capability to be coupled to form trains.

Cabinlift vehicles are of the same construction in principle whether used as personnel or cargo transport. These cabins have interior dimensions which allow passengers to stand. The capacity of the cabin is made up, therefore,

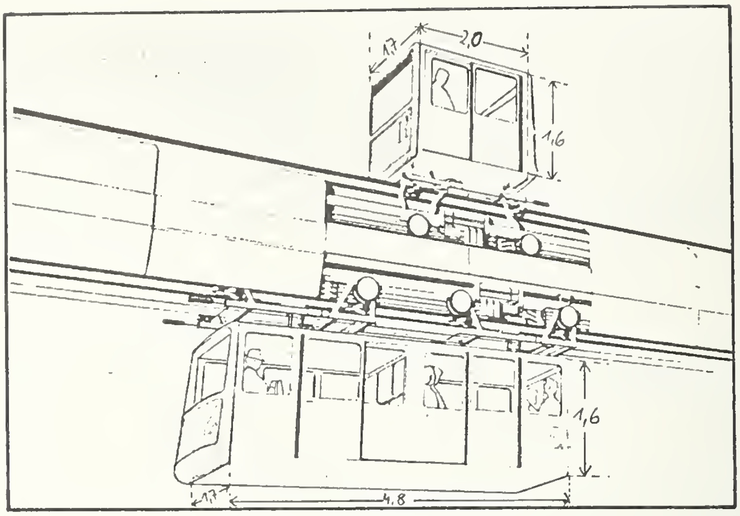


Figure 4-5. Cabintaxi KK3 and KK12

both of seated and standee passenger positions. Cabinlifts have been designed to date to carry between 12 and 50 passengers. In the station, Cabinlift vehicles stop directly against the platform and level with it. A special cabin scale prevents the vehicle from entering operation in an over-loaded condition.

The technological concept of all vehicles is to a large extent similar and will be briefly described below.

The cabins are constructed from extruded aluminum sections. Individual cross sections, finished plates, and extruded sections are welded to a framework and fastened with exterior planking. A fiberglass crash pad is built into the front section, which in case of a front-end collision absorbs a large amount of the energy, thus protecting the passengers from severe injury. Fire retardant materials are used for the interior component of the cabin. At the present time the doors of the Cabintaxi are manually operated accordion doors, while automatic doors such as those found in elevators are planned for the Cabinlifts.

The vehicles may be equipped with an intercom system to contact the operation center. It is planned that the vehicles be equipped with an emergency button, the pushing of which would cause the cabin to stop at the closest station. Electrical ventilation and heating of the cabins is thermostatically controlled.

The bogie of the small 3-seat cabin consists of a single-drive assembly, while that of the KK12 cabin and Cabinlift consists of two drive units. (See Figure 4-6.) The bogies are designed as exterior running bogies, that is, they span the cross section of the carrier track.

Each bogie has four wheels which act as guidance wheels and four others acting as carrier wheels. The carrier wheels are doubled or twinned on the hanging (or suspended) vehicle rail in order to be able to negotiate the central sections of the switches. For control over switching areas the bogies are equipped with an extra set of horizontal switching wheels for selection of travel direction (left or right at switches).

For propulsion, each bogie has two asynchronous horizontally mounted double-sided linear motors, which are regulated with the help of a phase section controller. In addition, control by means of a frequency inverter was also investigated. The two types of motors presently used propel the Cabintaxi at speeds of from 10 to 12 m/s and the Cabinlift at from 5 to 8 m/s. Operational speed of the Cabintaxi is 10 m/s.

For acceleration and braking the linear motor uses a controllable retifier in a 3-phase bridge circuit.

In the higher speed ranges the speed is refuced electrically by the linear induction brake. The wheel drum brakes are activated at low speeds and also serve for reinforcing emergency braking and as holding and stopping brakes. In case of power failure, the wheel brakes are supplied by an on-board battery.

In case of power failure, the wheel brakes are supplied by an on-board battery.

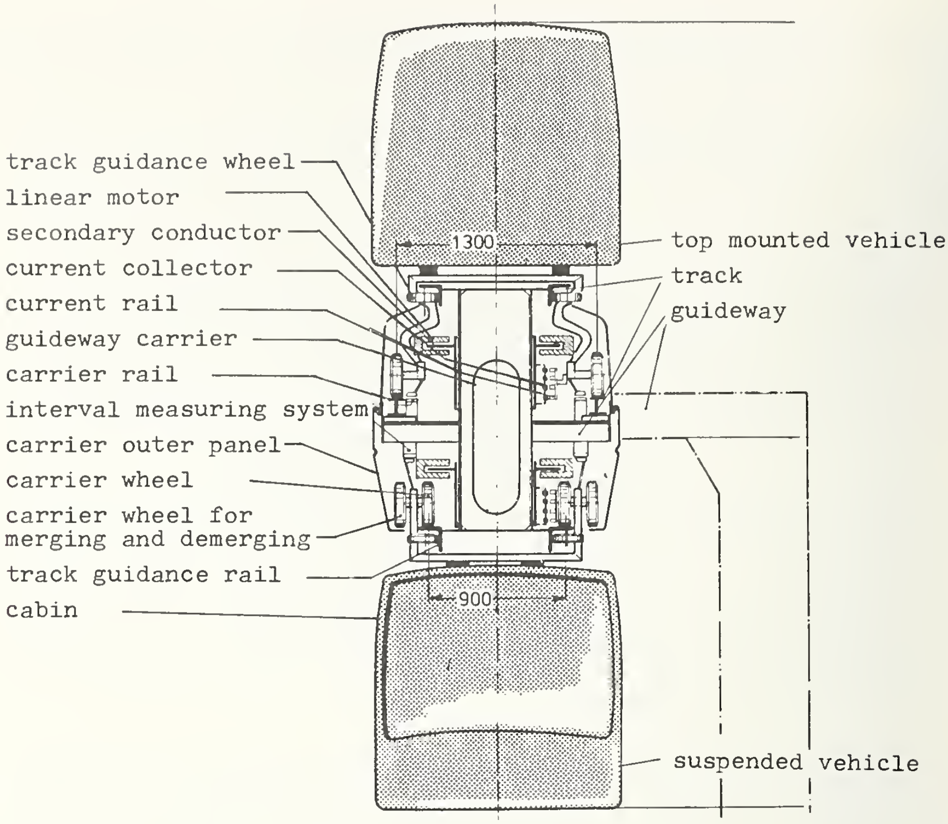


Figure 4-6. Bogie and Guideway Beam

The control elements of the vehicle, such as headway measuring electronics, mission logic, etc., are located in the cabin beneath the seats. The transmitter-receiver (and planned safety monitoring antenna) are installed in the bogie.

Guideways

An elevated double track system is planned as the typical guideway for the Cabinrail system. This design could also be used within tunnels. Top-mounted vehicles and suspended vehicles going in opposite directions use the same beam. The guideway can also be constructed as a single track (suspended or top mounted) as shown in Figure 4-7, according to the requirements of the city and other parameters regarding the transport situation.

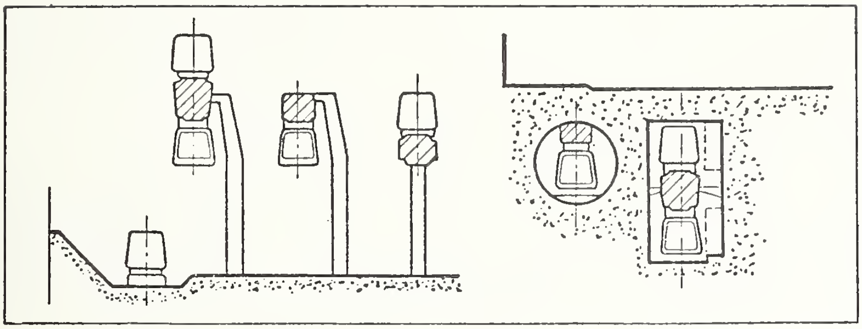


Figure 4-7. Guideway Diagram

The guideway beams consist of a rectangular steel structure and the carrier and track guidance rails, as well as necessary auxiliary equipment. (Figure 4-6). The attachment of supply lines is also possible. An outer shield or plate running along the track serves as protection against weather and noise insulation, as well as improving the exterior appearance of the carrier. Carrier and directional guidance tracks, power rails, headway measuring cable, and reaction rails are required for each traffic level.

Hardly any wear takes place on the rails due to the rubber wheels. The power rails consist of four parallel I-form aluminum structures with a steel plating. The reaction rail is constructed of an aluminum structure and mounted at a 5 percent elevation on either side.

The beam supports are constructed of steel or concrete components. Six different types of supports may be used according to track design: cantilever arm, T-form, mushroom, goal post, or portal supports, as well as pylons. (These various designs are illustrated in section 4.3.3.) Short construction or installation time of the tracks can be accomplished by the use of prefabricated track elements. The distance between supports is 40 m for straight-line track, and 30 m on curves.

In connection with the determination of the vehicle size, the guideway beam cross section was also standardized. For the KK3 and KK12 cabins the specified profile has a cross section of 1760 mm width, with a height of 1830 mm. For the middle-sized cabins (MK) having a width of about 2 m, the profile measured width = 2280 mm and height = 2660 mm.

At the fixed switches the vehicle will be steered to the specified direction by means of a fixed form guide. At branching points special conductor rails are fixed to the track. A branching switch operated by a switching wheel located on the vehicle, achieves guideway control at these points.

The cross section of a two level Cabintaxi guideway affords an area of about 5.80 m in height and about 2.05 m in width (without supports). The Cabinlift with suspended vehicles requires a height of about 4.50 m and a width of 2.50 m. Since vehicle drive is accomplished independent of the frictional contact between the wheels and the rail, passenger comfort considerations become the main criteria in determining the dynamic operational performance, as well as design of the guideway layout. For vehicles in which the passengers cannot stand, the performance can approximate that of a normal passenger car; for Cabinlifts accommodating standing passengers, these dynamic limits are considerably lowered. The smallest track radii are therefore:

	v		R_{min}
Cabintaxi	10 m/s	.	30 m
Cabinlift	6 m/s	.	30 m

The radii are connected by spirals (Cabintaxi: A_{min} = 25 m). The largest allowable pitch is 10 percent, and in exceptional cases 15 percent is possible.

Stations

The decision for off-line or on-line stations must be made in consideration of the amount of traffic and the operational concept of a given Cabinrail system. For discretionary destination-operation with KK3 cabins, off-line stations are required for proper continued operation.

The number of docking points is dependent upon the amount of use expected of the system. If the double-track guideway is used with top-mounted and suspended cabins, then one has a two-level station with a platform for each direction (Figure 4-8).

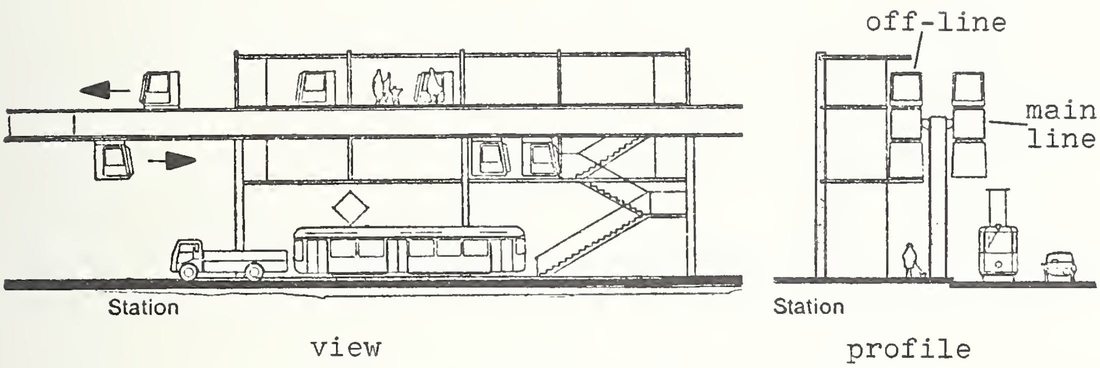


Figure 4-8. Off-line Station with Double Track Beam

In addition to fixed stairways, multi-level stations should be equipped with either an elevator or an escalator.

Safety equipment and passenger handling equipment (automats), as well as the station control unit are part of the station equipment. Installation of video monitors, emergency call boxes, or alarm systems and fire estinguishers, as well as emergency stop handles are planned to assure passenger safety.

In the passenger handling area, the ticket automats and information tables (network maps with stations illustrated) are set up. For specific destination discretionary travel the destination is coded onto the travel ticket. Each docking point along the station platform is equipped with a trip destinaation automat. Introduction of the travel ticket into the automat causes the cabin at that docking point to receive the destination information.

Operation Support

The Cabinrail system drive power is 50 Hz 500 v. The drive current for the Cabintaxi is taken from 10 KV power mains and fed to the system via substations.

The 4 pole power rail is normally mounted on one side of the track carrier. To protect against excessive contact voltage a protective conductor was selected. Two power collectors are fixed to either side of the vehicle. On the basis of extensive testing the useful life of the power collectors is estimated at more than 50,000 km, and with copper coated aluminum rails more than 100,000 km.

Specially designed multi-purpose repair vehicles are planned as recovery and rescue equipment for each system. The multi-purpose vehicle is designed for recovering passengers from a stalled vehicle and for small repairs. One or more of these types of vehicles would be stationed at points along the network depending on its size. The repair vehicle is stationed at a repair facility. It can be used to push or tow a defective vehicle.

Location of maintenance and storage depots is determined by the operational concept, as well as the site of the network, and the required response time.

4.1.4 Tabular Presentation of System Data

Significant Cabintaxi and Cabinlift characteristics are presented in the following tables. The detailed planning done for the Bremen Hospital System top-mounted guideway is used as an example for the Cabinlift system. (vehicle M18S).

	CABINTAXI SYSTEMS		CABINLIFT SYSTEM (BREMEN)
System Characteristics	KK3	KK12	M18S
Type of traffic service	many-to-many	axial and many-to-many	point-to-point (few-to-few)
Operational mode	discretionary travel	line transport/ discretionary travel	schedule transport/discretionary travel
Station arrangement	off-line	on-line/off-line	on-line/off-line
Train length	single vehicle	single vehicle/ 2 car trains/ multi-car trains planned	single vehicle
Privacy	yes	no	no
Transfer Necessary?	no	depending on operational mode	no
Intermediate stops	none	depending on operational mode	yes
Operational monitoring	TV	TV	TV
Transportation of luggage and baby carriages	yes	yes	yes
Transportation of freight	no	no	yes
Vehicle			
Length (m)	2.0	4.8	3.94
Width (m)	1.7	1.7	2.44
Height (m)	1.6	1.6	2.40
Coupling length (m)	2.3	5.2	-
Empty weight (kg)	900	2000	3000
Payload objective (kg) (max)	300	1000	1500
Operational weight (kg) (max)	1200	3000	4500

	CABINTAXI SYSTEMS KK3	CABINTAXI SYSTEMS KK12	CABINLIFT SYSTEM (BREMEN)
Sitting/standing places (-)	3/-	12/-	8/10
Space occupied per seat position (m^2)	0.7	0.45	0.4
Space occupied per standing position (m^2)	-	-	0.25
Total number of doors Doors per side	2 1	4 2	2 1
Door width (m)	0.68	0.68	1.40
Door Height (m)	1.4	1.4	2.0
Opening/closing procedure (man./mech.)	manual	manual	automatic
Step height (cm)	0.15	0.15	level entry
<u>Bogies</u>			
Number of bogies/ rotatable undercarriages	1	2	2
Number of carrying wheels, top-mounted/ suspended	4/8	8/16	8/-
Gauge			
top-mounted (mm) suspended (mm)	1380 1000	1380 1000	1600 -
Wheels	hard rubber	hard rubber	hard rubber
Number of guide wheels	4	4	8
Switching mechanism	4 switching rods	8 switching rods	8 switching rods
Location of steering rods	2 each side	4 each side	4 each side
Number of switching wheels	4	8	8

	CABINTAXI SYSTEMS		CABINLIFT SYSTEM (BREMEN)
	KK3	KK12	
<u>Propulsion and braking</u>			
Type of propulsion	D-LIM	D-LIM	D-LIM
Number of motors	2	4	3 (2 on one side V = 7 m/s (1 opposite V = 10 m/s
Power in (kw)	10	20	20[1] 40[2]
Energy use (kW/veh-km)	0.3	0.7	-
Operation voltage (V-AC)	500	500	380 or 660
<u>Type of braking</u>	D-LIB and drum brakes	D-LIB and drum brakes	D-LIB and hydraulic wheel brakes
Number of dynamic brakes	2	4	2+1
Number of mechanical brakes	4	8	6
Power supply	power rail with power collector	power rail with power collector	power rail with power collector
<u>Performance</u>			
Maximum speed (m/s)	10 (14)[1]	10 (14)[1]	7 (10)[2]
Operation speed (m/s)	10	10	7 (10)[2]
Acceleration (m/s^2)	2.5	2.5	0.35[3] 1.0[4]
Deceleration (m/s^2)	2.5	2.5	0.35[3] 1.0[4]
Emergency braking deceleration	5.0	5.1	1.5
Reaction time for emergency braking (s)	0.1	0.1	0.3
Maximum jerk stress (x/y/z direction (m/s^3)	2.25/1.6/-	2.25/1.6/-	-
Maximum uncompensated lateral acceleration (m/s^2)	2.5	2.5	
Maximum vertical acceleration (m/s)	1.0	1.0	-

1) v = 14 m/s in development test since June 1977
2) v = 10 m/s for other applications
3) b = 0.35 m/s^2 due to the transport of soup bowls
4) b = 1.0 m/s^2 for other application (standing passengers)

	CABINTAXI SYSTEMS		CABINLIFT SYSTEM (BREMEN)
	KK3	KK12	
Guideways			
Guideway beam	steel carrier	steel carrier	steel carrier
Beam type Double guideway/ Single guideway 1)	box beam	box beam	-
Height (m) Width (m)	1.83/0.90 1.76/1.76	1.83/0.90 1.76/1.76	-1.55 -/2.1
Guideway elements			
Minimum radius at maximum speed (m)	30	30	30
at reduced speed (m)	16	16	-
Minimum Spiral parameter (m)	25	25	-
Maximum banking (°)	5	5	-
Maximum grade (%)	10	10	4
Maximum grade with speed reduction	15	15	-
Interval between supports (recommended)	25-40	25-40	25-40
Type of switch	passive, branching switch in bogie	passive, branching switch in bogie	passive, branching switch in bogie
Min. switching radius (double track)	40	40	-
Min. switch interval (m)	24.5	27	-
Stations			
Number of docking points	4 max. 12	2 max. 6	2
Platform length (m)	10 max. 30	10 max. 30	8
Braking and accelerating spur track length (m)	27	30	85; 30 2)
Maximum possible vehicle backup Approach/departure	8/1	4/1	4/1

1) Single track, top-mounted
2) For other applications with v = 10 m/s

	CABINTAXI SYSTEMS KK3	KK12	CABINLIFT SYSTEM (BREMEN)
Average stop time (s)	15	20	passengers 20-30 freight 60
Travel ticket sales	automatic	automatic	-
Empty vehicle reserve (number of vehicles)	2 max. 6	2 max. 6	-
Stopping precision target point (± cm)	10	10	5
<u>Operational control</u>			
Headway control	asynchronous interval	asynchronous interval	asynchronous interval and block system
Number of blocks between vehicles	none	none	4
Max. interval (s)	1.4	1.6	14;11.0[1)]
Avg. waiting time for 90% of the passengers (min) (planned)	less than 1	less than 3	-
<u>Environmental stress</u>			
Exterior noise at 7.5m[1)] (dB(A))	60-65	65	-
Exhaust	none	none	none
<u>Capacity (per line)</u>[2)]			
Clear track sections			
Vehicles per hour	2571	2250	257
Passengers (max) (per hour)	7714	27,000	4626
Passengers (80% occupancy)	6171	21,600	3700

1) Equivalent constant noise level at 10 m/s at a distance of 7.5 m from the track.
2) See section 4.11

	CABINTAXI SYSTEMS KK3	KK12	CABINLIFT SYSTEM (BREMEN)
Switches			
demerging	same as clear track[1)]	same as clear track[1)]	-
merging switches	$Q_1 + Q_2 = Q_{clear\ track}$[1)]	$Q_1 + Q_2 = Q_{clear\ track}$[1)]	$Q_1 + Q_2 = Q_{clear\ track}$[1)]
Station			
4 docking points (2 docking points for KK12 and Cabin-lift)			
Vehicle (veh/h)	450	200	60
Passengers (max)(per/hr)	1350	2400	1080
<u>Safety and reliability</u> (goal values)			
MTBF station (h) with 24 h operational day	770	770	
MTBF Vehicles (h) for 10 h operational day	1920	1920	
<u>Projected useful life</u> (years)			
Guideway beams, supports, switches, and stations	50	50	50
Merging and demerging switch electronics	15	15	15
Elevators	15	15	15
Station control, central computer, control center	10	10	10
Ticket automats, video monitors and intercom systems	10	10	10
Vehicles	10	10	10

1) See section 4.11

4.2 CONTROL SYSTEM

4.2.1 Hierarchical Structure

In order to limit the effects of operational malfunctions, a three-level hierarchical control system is used for automatic operation of small cabin traffic (Figure 4-9).

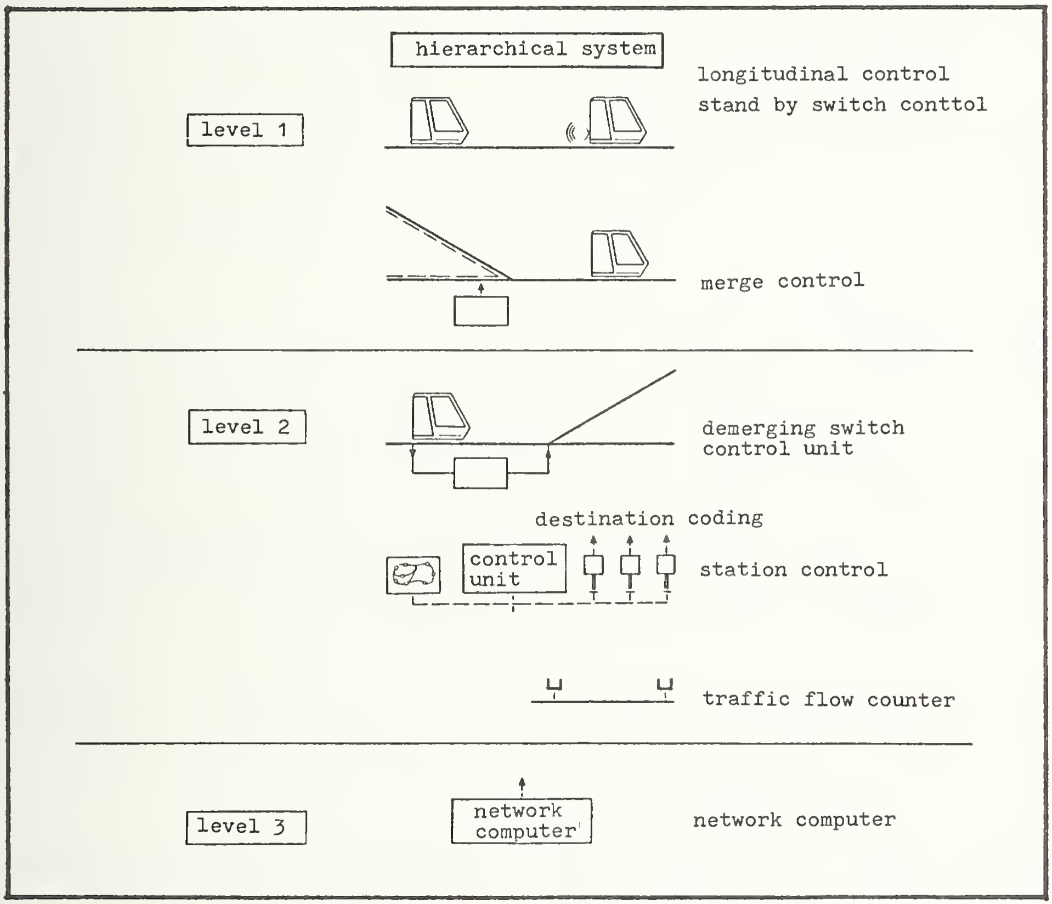


Figure 4-9. Control Hierarchy

The headway regulation and control of the merging switches constitute the first level in this system. On the next level are the control units for station control, the control of the demerging switches, and traffic density counters for that track. These two levels are interactive with the third and highest level, that is the network computer. The most important tasks at the third level are the disposition of empty cabins and control of traffic flow.

These three automation levels are technically decoupled. Failure of the network computer, for example, leaves the first level completely unaffected. If the network computer should suffer total failure, the function of the network would remain essentially intact, except for control of the traffic flow. Since the cabin platoon is stable, no interruption in the traffic occurs, although the performance of the total network could be affected. The situation is similar for the availability of empty cabins. This process would suffer a decrease in efficiency when controlled only by the station computer.

Elements within the individual levels operate completely in parallel. For example, each station and switch is equipped with its own control unit, the function of which remains completely independent of all other stations or switches.

4.2.2 Vehicle Control

Figure 4-10 illustrates a block structure of the vehicle control system. The entire arrangement is divided into 10 different blocks. One of the 10 blocks, the power supply, is not illustrated. Vehicle control tasks include the following: activation and/or steering control of the steering wheels, doors, mechanical brakes, linear motors, linear brakes, headway control transmitter, as well as less important, and therefore unillustrated components such as heating and lighting.

The block designated as "central control unit" is not further divided into sections. This unit dissipates almost the entire load supplied by the power supply and outputs two analogue (A), three digital (D), and three switching or gating signals (S). The necessary inputs aside from the power supply are vehicle speed, the interval measuring signal from both interval measuring cables (picked up by the two right and left receivers), and digital information which reaches the vehicle via data transfer. Vehicles are equipped with the various equipment necessary for the transfer of the interval measuring signal between vehicles and for the transmission of digital information to the subsystem on the next higher hierarchical level, that is, switch control and station control units. Contact between the vehicle and the highest level, the network computer, is accomplished indirectly via the middle level and in no case directly.

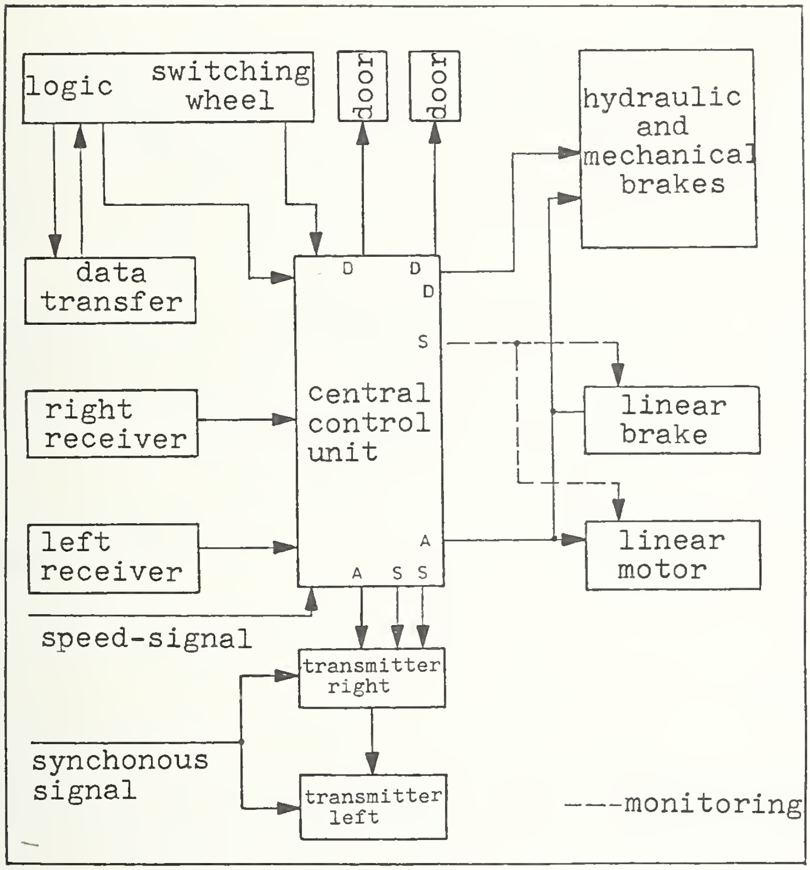


Figure 4-10. Block Diagram of the Vehicle Control

The interval measuring signal, which is important for safety, is transmitted between vehicles on a redundant system by left and right side receivers and transmitters located on the vehicles. Distance measuring is accomplished by the damping effect of the transmisssion cable located on the guideway. (At the present time this system, as it is installed at the test track facility, still has only one channel.) This longitudinal control system is also used for the merge control.

"Mission logic" supplies information concerning the vehicle trip destination data to the stations, as well as necessary information for the control of the demerging switches.

For recognition of the various kinds of sections along the guideway, such as switches, stations, etc., a transmitter/receiver unit is installed in the guideway which is sensed by the vehicle via its status recognition device. This in turn activates the necessary switches and circuitry for the headway control and mission logic.

The manufacturer continually conducts investigations into the effects of control element failure in order to improve safety. In addition, independent consultants are involved in assessing the development process. A redundant system incorporating a fail-safe monitor is planned for vehicle control. An overview of this safety concept is presented in Section 4.9.

A description and illustrations of the functions and communication equipment follow.

4.2.2.1 Headway Control

Function

The vehicle-to-vehicle distance measuring equipment, along with the speed control, is located at the lowest level of the control hierarchy. This system operates according to the following principle: a high frequency AC voltage is induced in a special conductor which has characteristics such that the signal is damped according to an exponential function with distance. Each cabin is equipped with a transmitter and receiver which respectively induce and receive an AC current in the interval measuring cable installed along the guideway (Figure 4-11). The electrical components on board the vehicles and the interval measuring cable installed along the guideway are planned to function along with a partially redundant fail-safe monitor to provide safe operation. The signal transmitted from a cabin is damped as it travels backward along the track to the next cabin. The amount of damping is dependent upon the amount of distance between the cabins.

In each cabin the trip is so controlled that a predetermined minimum distance dependent upon cabin speed (absolute minimum braking distance) is maintained from the preceding cabin. At the maximum speed of 10 m/s this minimum

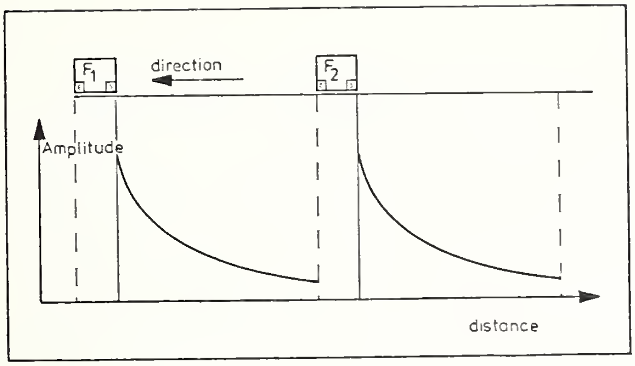


Figure 4-11. Amplitude Damping

interval between vehicles is 13.5 m. This distance decreases with decreasing speed and comes to a minimum of 0.2 m for stationary vehicles (Figure 4-12).

If the preceding vehicle is a large distance away, then the maximum allowable speed is maintained. In dense cabin traffic the interval is so measured that each vehicle can follow the accelerations and decelerations of his predecessor without his own acceleration or deceleration values exceeding that of the preceding vehicle. With this type of operation, application of the brakes in a given vehicle does not necessitate increasingly severe braking in the following cabin platoon, and braking decelerations remain in general in a comfortable range. Application of the brakes is done in a smooth, non-stepwise manner.

For proper regulation, in addition to the speed of a given vehicle and its distance from the preceding vehicle, the speed of the preceding vehicle must also be known. Speed is sensed by two tachometers located in the bogie. This information is conveyed by modulating the transmitted signal according to the speed the vehicle is traveling: the higher the speed, the lower the transmitted amplitude. In this way a vehicle at short interval traveling at a high speed appears the same as a vehicle at a larger interval traveling at a lower speed. In case of power failure, headway regulation and wheel brakes obtain their necessary energy from an on-board battery.

Figure 4-12. Vehicle Platoon at v = 36 km/h and 1.4 s Headways

The signal resulting from the interval measurement is compared with a speed dependent desired value by the vehicle control unit. The vehicle control unit transmits a control signal for propulsion of the vehicle depending on the difference of the two signals.

Headway Control Calculations

The interval algorithm for the Cabintaxi can be expressed in general as follows:

$$(1) \quad d = a_o+a_1v_2+a_2v_2^2+a_3v_2^3+c\ (v_2-v_1)$$

v_2 = speed of the following vehicle #2

v_1 = speed of the predecessor vehicle #1

a_o, a_1, a_2, a_3, c = constant parameters

The first part of this equation represents the absolute minimum braking distance of a vehicle.

$$(2) \quad d_{statt}(v) = a_o+a_1v+a_2v^2+a_3v^3$$

When both vehicles are traveling at identical speed the equation reduces to

$$(d = d_{statt}\ (v);\ v_1 = v_2 = v).$$

This equation also yields the guideway section capacity as discussed in Section 4.11.

The absolute braking distance given in equation (2) above represents a modification of what was originally derived in (2) to account for a safety factor in the event of exceptional operational conditions. Two cases are given in (2) for the determination of the absolute braking distance.

Case a) Cabin 2 with partially defective brakes, and therefore low braking deceleration, approaches cabin 1 which is undergoing emergency braking deceleration. Cabin 2 brakes with comfortable deceleration and a braking distance of X_B, while cabin 1 under emergency braking conditions has a braking distance of X_N.

Case b) Both cabins travel with velocity v. The first cabin is brought to a sudden stop (for example, by a tree laying across the track, etc.). Cabin 2 then brakes with emergency braking deceleration and braking distance of X_N.

In both cases, cabin 2 is effected by a time delay t_f between the time when the first cabin's situation is sensed and when the brakes can be applied. If one assumes that the normal braking distance X_B is approximarely double that of the emergency braking distance, then

$$\frac{X_B}{X_N} \sim 2$$

Therefore, in Case a the required relative braking interval is equal to the absolute braking interval in Case b (see Figure 4-13). The open distance a_v between vehicles becomes

$$a_v = v \cdot t_f + X_N \quad \text{or with}$$

$$X_N = \frac{v^2}{2\, b_N} \quad (b_N = \text{emergency braking deceleration})$$

$$a_v = v.\ t_f + \frac{v^2}{2\, b_N}$$

which accounts for the linear and the quadratic terms in (2). The modification includes the addition of the third order term to account for jerk and the use of an appropriate emergency deceleration.

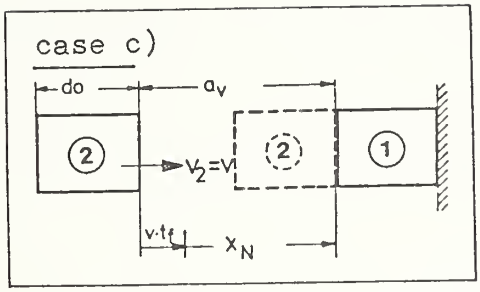


Figure 4-13. Braking Distance for Case b

When vehicles are traveling at different speeds the interval with the preceding vehicle is also dependent on speed difference. The expression $c\ (v_2 - v_1)$ describes the overtaking of a slow vehicle by a faster one. The values for a_o, a_1, a_2, a_3 and c determine the distance at which the following vehicle with velocity v_2 must begin braking when approaching the preceding vehicle with velocity v_1. With increasing speed difference, the minimum distance between vehicles also increases. This allows light usage of the brakes with small initial decelerations.

In the case where v_1 is greater than v_2 (for example, a starting platoon), the appropriate interval in d_{stat} (v) is added so that the absolute braking distance is not violated.

Equipment Description

The cabin is fitted with a transmitter and receiver on both the left and right sides for headway control. Interval measuring cables for transmission of the signal are located on both the left and right sides of the guideway. (Figure 4-14).

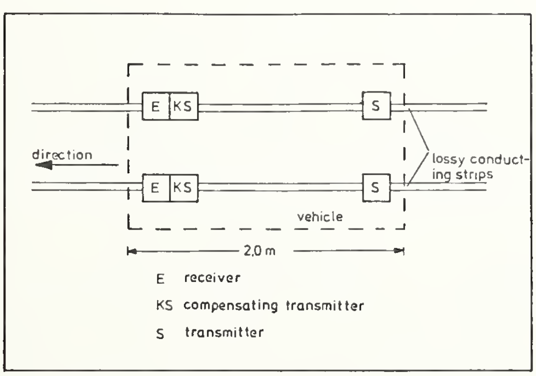


Figure 4-14. Arrangement of the Headway Control System Elements

A complete headway control system consisting of interval measuring cable, transmitter, compensator, and receiver is located on either side of the vehicle. This constitutes a fully redundant system over free sections of track. (The headway control in the cabins at the test track facility in Hagen has only one channel.)

Each of the two processing channels receives an interval signal and selects the smaller interval d_{ist} (see Section 4.2.3). A function generator creates for every d_{ist} value an appropriate speed value v_{soll} which is determined by the highest speed value v_{max} allowed along that section of track. The v_{soll} signal subsequently is given to a ramping generator which limits the acceleration of the vehicle to $+2.5\ m/s^2$ and $-6\ m/s^2$.

The interval measuring cable was originally made from a homogeneous carbon-based conductor, which proved to be sensitive to inclement weather, and because of the resultant tendency to pick up interference, it had to be replaced by a new conductor system. This consisted of three 0.5 cm thick copper conductors spaced at intervals of 7 cm. The cables are connected every 10 cm with discrete resistors (Figure 4-15). These resistors cause the signal to appear in discrete steps along the cable. By spacing the resistors a distance which is equal to that of the coupling element aboard the vehicle the signal stepping is evened out, and the conductor appears to be homogeneous. The damping value of the new conductor is 1.35 dB/m. This value is assigned a tolerance of less than 1 percent. Parallel ferrite slugs spaced 2.5 cm apart were installed behind the conductor in order to complete the magnetic path. The entire cable with resistors is sealed in plastic to protect against the effects of inclement weather.

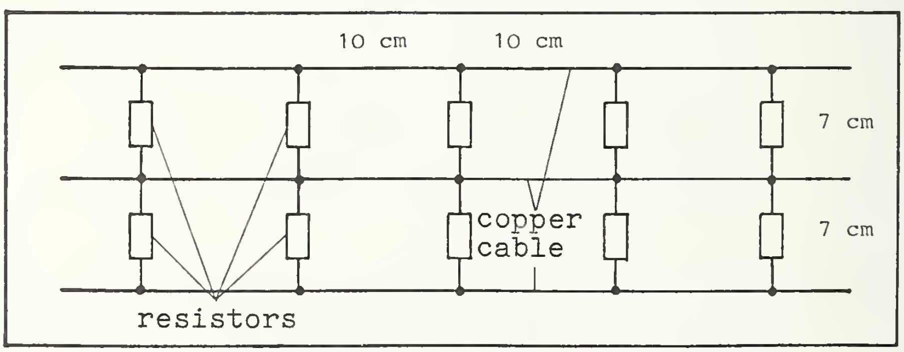


Figure 4-15. Interval Measuring Cable

The interval measuring cable performed satisfactorily in operations at the test facility during both vehicle platoon operation and switching operations.

Transmitters and receivers aboard the vehicles are fed from a 24-volt power supply. For emergencies a battery is available which can also feed the control unit and emergency brakes.

In addition to the interval signal transmitter which works at a frequency of 100 kHz, the vehicles are also equipped with compensation transmitters which are fed from a common modulator (Figure 4-16). The compensators transmit a signal with a phase shift of 180° which compensates for that of the transmitter. Compensators are installed between the transmitter and receiver and shield the receiver from signals transmitted from the same vehicle. In addition, this equipment shields preceding vehicles from interference from behind.

Tolerance for the distance between the vehicle antenna and the interval measuring cable is presently ± 6 mm in the vertical direction. This tolerance is quite small and may cause a loss in precision of the transmitted interval signal due to movement of the vehicle or inaccurate laying of the measurement cable. Delayed reaction of the vehicle regulation system could result, and this must be considered in the terms of its possible effect on the operational quality of the vehicle. At the present time new antennas are being developed which have increased tolerances.

In the spring of 1978 a fail-safe monitor system required by the appropriate German safety regulations is to be installed on the headway control system.

The function of the transmitter antenna, as well as the condition of the interval measuring cable along the guideway, is monitored by this system. The sensor is coupled to a fail-safe comparator which detects any failures in the system (Figure 4-16).

The monitor picks up the signal which is being transmitted to the rear of the vehicle, and after rectification this signal is fed to the comparison circuit. Failure in the functional circuit or interference on the interval

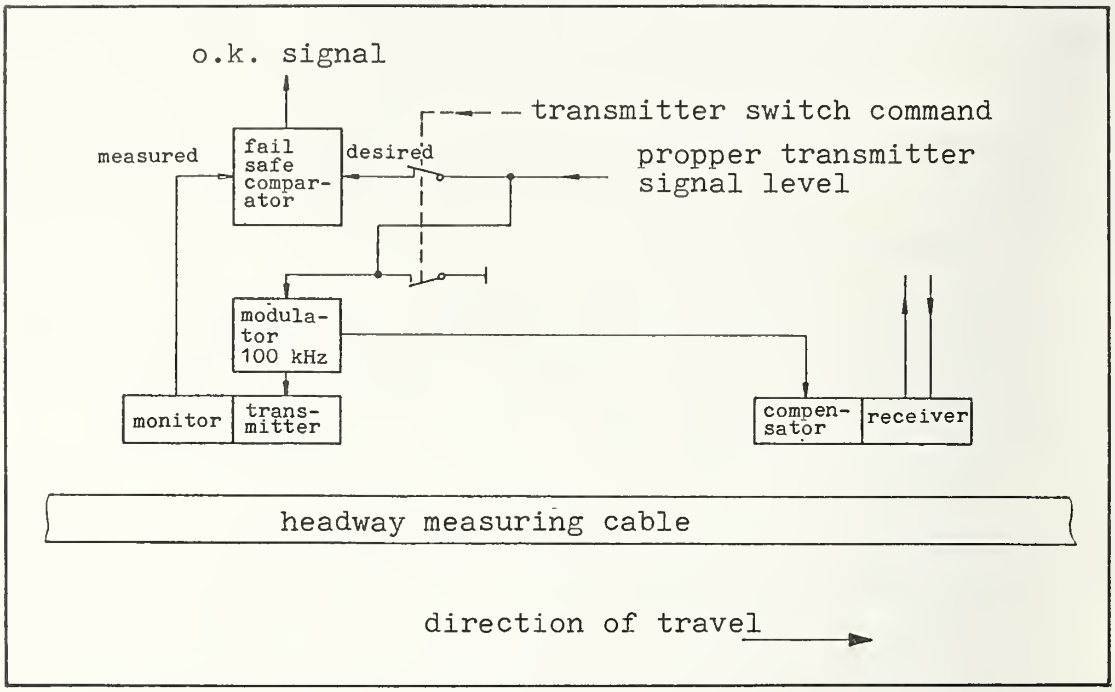


Figure 4-16. Transmitter Monitor Source: [53]

measuring cable, would cause the balance between these two redundant signals to be disturbed, and the "o.k." signal or flag would be switched off.

Although most failures of the interval measuring cables would be detected by the on-board transmitter monitor, additional protection against a break in the conductor along the interval measuring cable is required. It was planned that this would be done by measuring the voltage drop of a DC current fed into various sections of the cable.

A fail-safe monitor is also planned for the redundant headway control receivers.

For the recognition or detection of a non-transmitting object and/or vehicle (for example, caused by a defect in a non-redundant area of the system such as is found near stations or switches), the installation of passive microwave reflection equipment is being considered. The reflection of the waves on this equipment under normal circumstances would be neutralized. At the

occurrence of certain failures on board the vehicle (for example failure in the headway control system), the reflection element would be modified making the cabin "visible" to the following vehicle.

Other detection methods for a "dead cabin" are still under development. Two methods being considered are the "moving block" and the "vehicle recognition method."

In the moving block method the track sections would be divided into intervals that are so short that only one vehicle can occupy each block. A block presents no danger to an oncoming vehicle when it is unoccupied or when it is occupied by a vehicle which is transmitting an o.k. signal. At each block a "go signal" could be transmitted to the vehicle. This signal would only be transmitted if the six blocks ahead reported themselves as "safe." (This interval of track corresponds to the emergency braking distance from the highest speed including delay times, dead times, and tolerances.) This moving block principle has been determined to be fail-safe by the Technical University of Braunschweig as long as the entry permission information (for example, the o.k. signal from a vehicle or a switch) has fail-safe characteristics.

Vehicle recognition was also investigated. This principle would be based on the individual situation recording of all vehicles on a given track section to a base control station. From all vehicle recognition information available to the monitor, it could be determined that each cabin is transmitting the correct interval information. If no guideway failures could be detected (for example, broken or disconnected interval measuring cable or defective switch), a drive permission signal is given by the base control station.

4.2.2.2 Mission Logic

The mission logic stores the destination information, controls the demerging switch, handles vehicle data, and operates the doors in the stations. The station transmitters and receivers exchange data regarding the vehicle, such as whether the door is open or closed, and the heating is on or off. Transfer of monitor data with information from the fail-safe comparators, which would indicate any failures aboard the vehicle, is also planned (Section 4.97). Mission logic also makes decisions regarding which vehicle reaction is to be taken, for example, an automatic trip to the repair facility or be pushed away by a following vehicle.

At the demerging switches the destination code is transmitted from the vehicle to the station via the wayside transmitter/receiver unit. The vehicle then receives a signal from the station, indicating the proper setting for the steering or switching wheels aboard the vehicle.

In the station the vehicle is stopped by a signal from the destination braking transmitter which works by effecting the headway control system on one side of the vehicle. During entry to the station both vehicle receivers are active. For departure, the destination transmitter is switched off from a "free-start" signal provided by the mission logic. The vehicle can then depart the station as long as it is unhindered by a preceding vehicle. After leaving the station the transmitter is switched on again.

The signal transmission of mission logic is accomplished on a carrier frequency of 5 and 8 MHz. The mission logic is non-redundant.

4.2.2.3 Status Information

For recognition of the various types of track sections, such as merging switches, stations, etc., transmitters/receivers are installed along the guideway which the vehicle senses via its status information equipment. At the present time status recognition is only operational at discrete points.

The antenna used for transfer of status information is in the forward part of the left distance measuring transmitter. The signal transfer is accomplished with a 6-tone structure in a band width of from 300 Hz to 4 kHz. 20 different signals are possible using a 3-out-of-6 code. Six types of track sections are: Free sections, merge point (with deceleration limiting), demerge switches, and stations. The two unused codes are called unlimited merge and a reserve.

Entrance onto a new track section is signaled by the transmitters/receivers along the guideway.

In normal operation on open track the headway control system on either side of the vehicle is switched on. The deceleration limiter is switched off. Switch positions are represented by the following table:

Status \ Components	Transmitter & Compensator		Receiver		Acceleration Limiter	
Clear track	x on	y on	x on	y on	x off	y off
Station	x on	y off	x on	y off	x off	y off
Merging	x on	y off	x on	y on	x off	y on
Demerging	x on	y off	x on	y off	x off	y off
x is the side of the vehicle where the switching wheel is activated, y is the opposite side.						

4.2.3 Switch Control

The function and technology of the switch control as a component of the second level in the hierarchical control system is discussed in this section. The technical structure and mechanical function of the passive switches and their interaction with the elements on board the vehicle for the accomplishment of switching operations are presented in Section 4.4.

Demerging Switches

The control of the demerging switches is accomplished by a transmitter/ receiver unit which is installed on the guideway in front of the switch, and is connected to the station by a control unit. In this way the use of electronic equipment along the guideway is reduced and the maintenance of the control system is simplified. The destination address which is stored in mission logic while in the station is inductively read early enough before the switch to allow the station unit to make the proper switching decision. The control unit contains a list of all destination addresses which can be reached from the given switch. The list consists of a bit-vector which is reduced to several sequential 8-bit bites. Each station is assigned bits according to its number (Figure 4-17). If the bit is set to ("1") then the destination station is to be reached on the left branch.

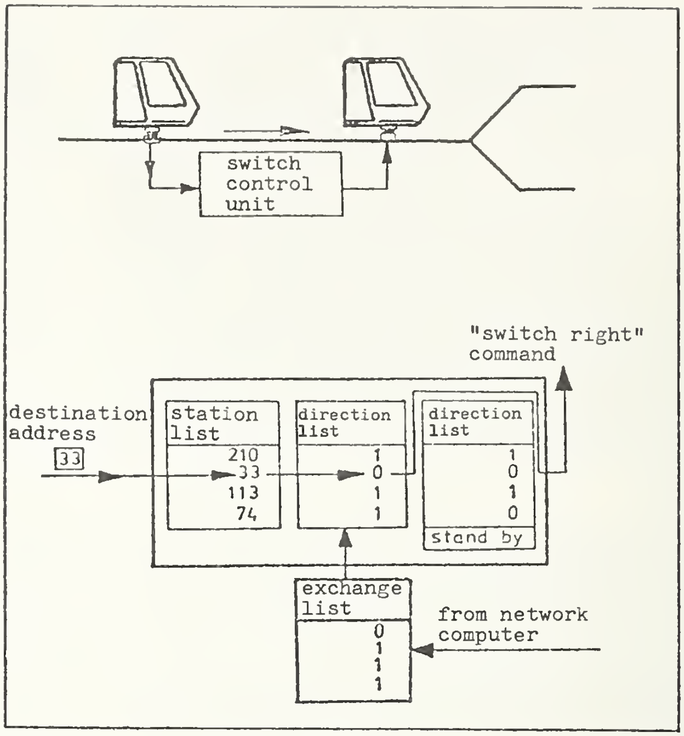


Figure 4-17. Switch Command Lists for Demerging

Depending on the selected direction for continued travel the status information unit switches off the headway control on the side of the vehicle for which the switching wheel has not been activated (interior side of the switch). (See Section 4.2.2.3.) The headway control on the other side remains in operation. In this way a vehicle which is stopped just beyond the demerging switch does not have the effect of backing up vehicles passing it on the main line.

This list of switching commands can be exchanged by the network computer any time when rerouting is necessary.

A hard wired standby direction list which displays the shortest route to a given destination is utilized in place of the exchangeable direction list in case of network computer failure.

If a vehicle entering a branching switch has no coded destination, it is recognized as an empty vehicle and controlled by a "guideway switching word". This word consists of 16 bits. The ratio of the number of zero (0) bits to one (1) bit determines the disposition of the empty vehicle; either to the right or to the left branch. The most significant bit in the guideway switch word is the switching bit; left (1) or right (0). After the empty vehicle passes the switch the switching word is cycled to the next bit position. The switching word is determined by the necessary disposition of empty vehicles (also see Section 4.2.5.1).

Merging Switch

The control of the merging switches has been developed on the basis of extensive simulation testing (Section 4.13), especially with regard to switch failure.

For merging, the headway control system, which is on the lowest hierarchical level of the control system, is utilized. By means of a non-redundant complex electronic installation, a vehicle is mirrored in the parallel track as a virtual image. This mirrored vehicle can be seen by the headway control equipment of real vehicles on the other leg so that the proper interval is accomplished and maintained before actual merging at the switch.

This mirror imaging is accomplished by the interval measuring cables on both guideway legs from a distance of 60 m before the actual merge point. Information is mirrored from track to track in 2 m segments. Parallel points on the two legs of the switch are connected for transmission and reception of distance measuring information by wiring which is laid from one branch to the other across the actual merging point along the guideway (Figure 4-18). At the V-point in the switch a total of 60 twin lead cables are bound together producing a cable diameter of 7 cm.

Upon entry into the switching section, the necessary switching for the headway control system, as well as an additional deceleration limiter, is carried out by the status information equipment (see Section 4.2.2.3):

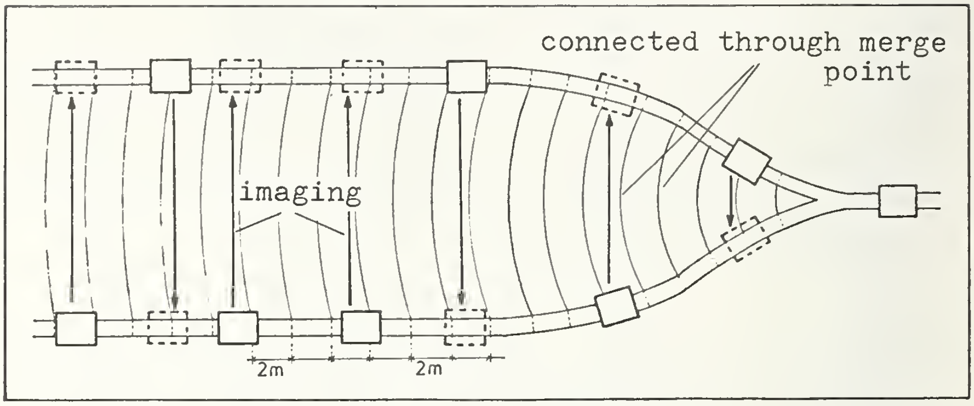


Figure 4-18. Schematic Representation of the Merging Switch

The transmitter and receiver on the exterior side of the switch will continue to function normally. On the interior side of the switch, however, the receiver is set to detect the virtual image of preceding vehicles. This mirroring effect is transferred from the real distance measuring cable on one arm to the virtual distance measuring cable on the other arm of the switch (Figure 4-19).

In order to avoid unnecessary emergency braking in an extreme situation (for example, the sudden appearance of the mirror image from a very close vehicle) the status information equipment in the headway control activates a deceleration limiter ($b=2.5\ m/s^2$) at the beginning of the merging switch section. In the first 30 m of the merge, the so-called "soft virtual image range" the control unit determines the serial order of the vehicles, and makes a primary/secondary decision upon their entry into the merge. The information for this continued travel decision is supplied by fixed reed relays on the track which are switched by permanent magnets mounted on the vehicle as it travels by. When the vehicle enters a 2 m segment the field of which

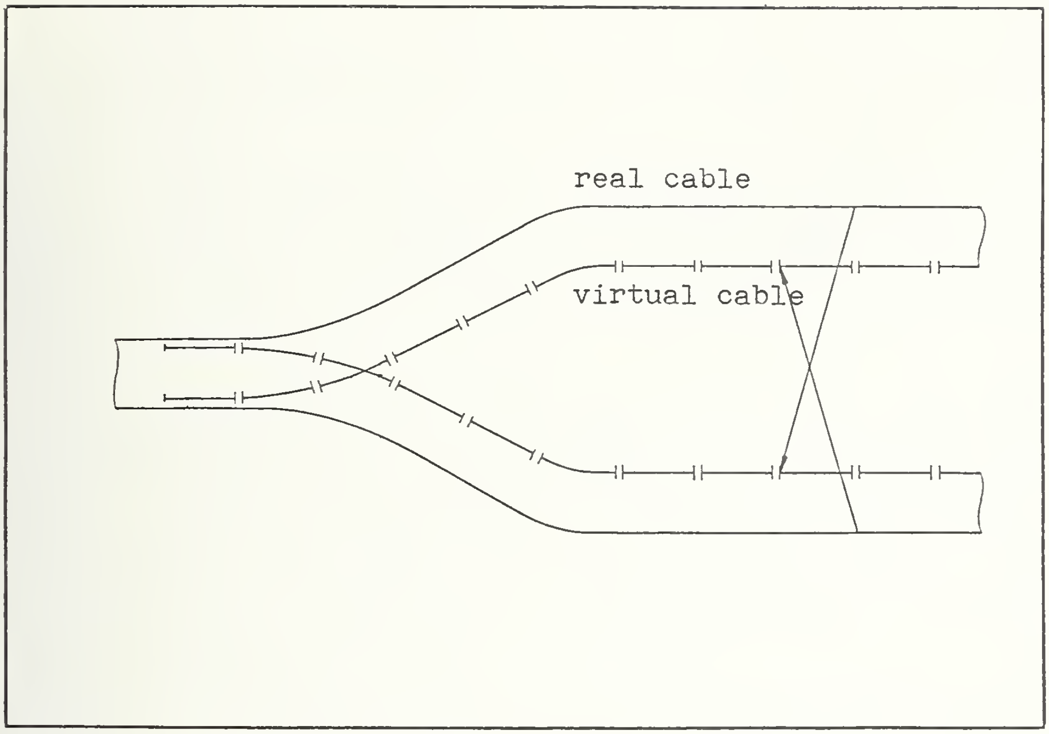


Figure 4-19. Interval Measuring Cable Configuration of the Merging Switch

is occupied by a vehicle on the other arm, the vehicle on the other arm is then designated as primary, and the secondary vehicle as secondary. That is, the first vehicle to enter a field on either arm of the track is designated as primary. The signal unit is set so that the secondary vehicle receives a signal from the primary vehicle, but not vice versa (Figure 4-20).

The signal in a "soft virtual image range" (as opposed to the "hard virtual image range") is damped by a special damping circuit and then mirrored to the other arm of the switch. The virtual preceding vehicle then appears to the following vehicle as if the interval is larger than it really is. At the beginning of the "hard virtual image range" the damping is decreased to 0 (Figure 4-21).

This "soft virtual image range" avoids the appearance of a "very close" virtual vehicle and serves as a smooth extension of the necessary intervals which would otherwise be caused by the application of brakes aboard the secondary vehicle.

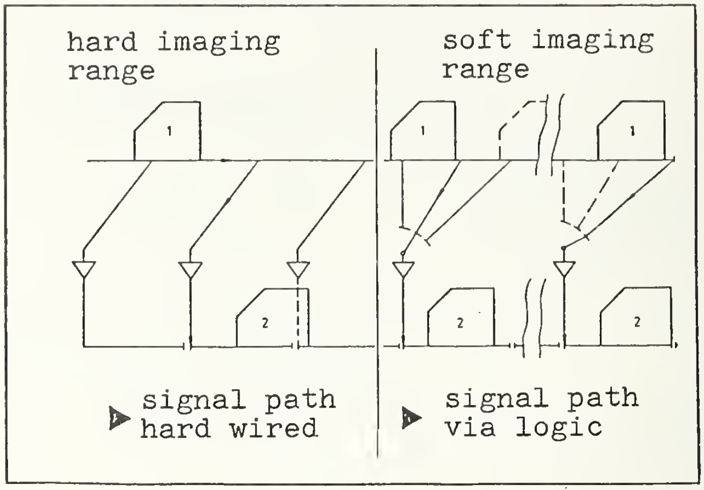


Figure 4-20. Principle of the Virtual Image

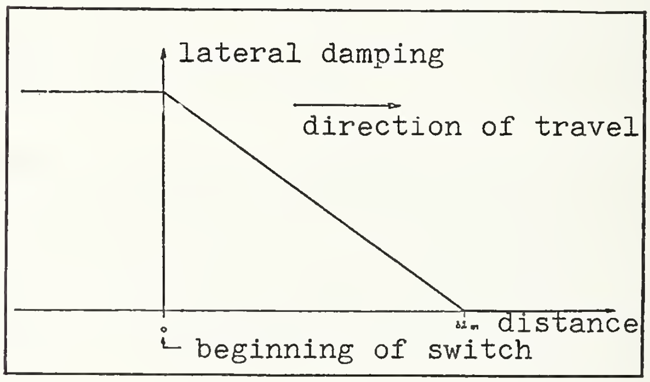


Figure 4-21. Decrease in Damping (as a function of distance from the switch)

Along the subsequent 30 m of the "hard virtual image range" the signal is transmitted over a hard wired system by means of amplifiers.
Each vehicle influences the following vehicle on the other switch arm as if both vehicles were on the same guideway segment. The deceleration limiter is switched off upon entrance into the hard virtual image range. The deceleration reaction to virtual vehicles is now carried out exactly as it would be on the open track.

With respect to merge control, a distinction must be made between free merging (symmetrical merging), which is the merging of two comparable vehicle streams, and station merging (asymmetrical merging) which is the insertion of starting vehicles into the stream from an off-line station. Both types of merging switches are installed at the test track facility. Investigation into the behavior of vehicle platoons in switching areas has shown that the maximum number of vehicles which may be handled by the switch (switch capacity) is always equal to the maximum guideway capacity on the open track. (Section 4.11).

The switching electronics on the test track are non-redundant. However, in the area immediately preceding the V-point in the switch, redundancy is provided by utilizing additional reed switches in the guideway and separate electronics to detect a potential conflict. One vehicle will be stopped by injecting a high-level signal into the "real" distance measuring cable. The manufacturer has demonstrated the function of the merge on the test track by merging vehicle platoons on each leg of a merge.

Further development of this technique has the objective of producing a switch safety unit which meets the fail-safe monitor specifications of the German Technical Supervising Authority (TÜV).

4.2.4 Station Based Control

The function of the station control has already been discussed in previous sections and is presented here as a summary.

The station control unit can be viewed as a connecting link between the higher and lower hierarchy levels. It operates in close connection with mission logic aboard the vehicle (Section 4.2.2.2), and it is also coupled to the network computer.

The destination code is transferred to the cabin via the mission logic, and in the opposite direction the station unit receives vehicle data. A vehicle failure monitoring system is being planned that will also utilize this link for transfer of data regarding vehicle defects. Depending on the type of failure reported by the vehicle, station control could be designed to react in various ways, for example, instructing an independent trip to the maintenance facility or removal of the vehicle from the main line.

The station control also controls the vehicle during demerging operations (Section 4.2.3). The destination address, which is stored in mission logic, is inductively read as the vehicle approaches the switch, and station control makes the necessary adjustments. The unit is supplied with a direction listing. In this list is a bit for every destination station which can be reached via a given switch. The resultant left/right signal is transferred to mission logic to control vehicle switching.

The direction lists can be exchanged by the network computer when a re-routing is necessary. Upon failure of the network computer a hard wired list giving shortest way information is utilized.

Station control, furthermore, determines the disposition of empty cabins. When no empty vehicles are available at the station the station controller calls for empty vehicles over the network computer. If an excess of empty cabins is available, the station control will send to the vehicle (thru the mission logic) destinations which are determined by the network computer.

4.2.5 Operational Procedure

As mentioned in the introductory section (Section 3.4.4.1), the Cabintaxis KK3 and KK12 and Cabinlifts are designed for different types of operation. The 3-seat Cabintaxi vehicle is designed for specific destination, discretionary travel; the 12-seat cabin is designed for scheduled route traffic, but can also be used for discretionary travel. The 12-seat cabin is additionally applicable to a more or less specific transport mission, i.e. scheduled transport with discretionary stops, or transport on discretionary lines. For the Cabinlift the combining of scheduled transport and discretionary travel is planned.

4.2.5.1 Discretionary Traffic to Specific Destinations

Operation

Automatic vehicle travel to a specific destination (without intermediate stops) is accomplished by loading destination station codes into the vehicle. For this reason the destination is coded onto the travel ticket.

The empty cabin will be brought to the platform by appropriate action of the computer. By introduction of the travel ticket into the destination automat, the destination code is inductively loaded into the cabin, that is, the code is retained in an internal memory unit aboard the vehicle. The door opens and the cabin is ready for operation. After pushing the start button in the vehicle, the cabin door closes and the vehicle departs the station. The following empty cabins advance in unison. Boarding and deboarding is possible at each docking point along the platform.

On the off-line station ramp the vehicle accelerates to an operational speed of V_{max} = 10 m/s, and is subsequently merged onto the main line. The cabin steers to its destination independently. Upon reaching the destination station, the vehicle leaves the main line, enters an off-line ramp, decelerates and slowly approaches the platform.

Optimization of traffic flow

The central network computer would be assigned the task of optimizing the traffic flow at the highest data level. It must regulate the load on each track section as well as handle the disposition of empty vehicles.

It is planned that the computer be constantly informed with regard to the traffic situation on individual sections of track by counters.

After consideration of traffic density on all sections, the shortest route would be sought for all origin/destination combinations. Since regulation of the network loading would be accomplished quasi-continually, the optimal route for a vehicle could be quickly changed during the journey. The new route would be realized by appropriate control of the branching switches. In case of problems along a given section of track, detours could quickly be arranged.

Disposition of empty cabins

Empty cabins are dispatched by the network computer according to the traffic requirements on the network. The computer is constantly informed with regard to the latest location of empty cabins, as well as the expected number of passengers at the stations. In case of a cabin shortage at a station, vehicles are called from the depot or from other stations which have an excess number of cabins. The number of cabins already on the network, as well as the resultant trip time to the station where they are required, is taken into consideration.

The disposition of empty vehicles around the system is controlled by the network computer according to an algorithm designed to minimize passenger waiting time. The strategy to be followed by that algorithm is in the simulation stage, but could be based on either maintaining a specific number of empty vehicles in a system loop section, or by controlling the number of empty vehicles in a general system section by commanded switching at demerge points.

After a given time interval (for example, 6 min) the situation could be reassessed and adjusted to accommodate any change in passenger requirements.

4.2.5.2 Scheduled Route Traffic (Line Transport)

For cabins running only under a scheduled mode the operational considerations, as well as the fundamental and technical options are similar to those required for automatic conventional rail operation. Operational dispatching is accomplished automatically by a computer. The passenger areas are monitored on a central video unit. From this central location the technical functioning of the passenger equipment can also be checked.

A feasibility study performed for the C-Bahn in Hamburg [4] is an example of a route traffic system which can also be used as discretionary transport. In this system the cabins stop only at stations where they are required, i.e., not all vehicles traveling over the same section of track will stop at all stations along that track section. Each passenger must give his destination. This destination is then displayed at the vehicle docking place.

As a result, a vehicle having that destination on its route would be ordered into the station. When more than one of the vehicles in the system have the same destination via different routes, the first vehicle which passes is called into the station.

A vehicle approaching a station stops when one of the passengers has specified that station as his destination (see below), or when ordered to stop by the station. In the latter case, the vehicle only stops when the vehicle has at least one free place. Within the vehicle the name of the next station is displayed; and the passengers could express the wish to stop at the next station by pushing a button marked "stop at the next station".

4.2.5.3 <u>Integration of Scheduled and Discretionary Traffic</u>

This form of operation is primarily seen as being effective for Cabinlift facilities (transport systems for hospitals, factories, fair grounds, etc.). The network computer receives all information concerning the schedule, passenger requirements, and the actual situation on the network. This makes possible the control of the vehicles in route, the efficient disposition of the vehicles, and display of all necessary information in the stations, as well as on-board the cabins.

When operating on a schedule the planned time of the next departure is displayed at all of the stations. The actual start of the journey is initiated by a "ready-to-start" pushbutton at the station. In this way the transport schedule can be continually suited to the working environment, for example, in a factory or hospital facility. This way scheduled transport can be considered as a demand-type of operation with fixed departure times.

The central computer also receives calls for necessary high priority or emergency trips and makes the necessary operational changes.

All requests for transport are arranged into various priority levels in the scheduling. Upon completion of an assignment, the vacant vehicle proceeds to the station having the next highest priority call. When, according to the schedule, no assignments are pending, the empty vehicle would then remain at the last destination until another vehicle requires that docking point or wishes to travel through that station (in on-line traffic). In this case the empty vehicle travels by each station having no specific destination until it encounters a station where it is needed. Otherwise, it continues on to the depot.

The stations are equipped to meet the requirements of such a system as follows:

- A pushbutton panel similar to that found in an elevator to call vehicles for discretionary travel;
- Equipment for reading magnetic cards used for calling vehicles in the scheduled transport mode, as well as the equipment necessary to program cards for special routes. This magnetic card equipment also serves to limit the number of people who may make high priority calls for vehicles;
- Control units for dissemination of information and its transfer to central control and to the vehicle by means of inductive data transfer;
- Information tables for the announcing of arriving vehicles, as well as the type of transport they are engaged in and their origin and destination;
- Inductive data transfer between the control unit and the vehicle.

4.3 GUIDEWAYS

The guideways can be equipped as double or single guideways (each having a top-mounted and/or suspended rail). Normal construction is as an elevated unit. However, it is possible to use this design in tunnels.

The construction of the guideway beams for the different system variations is in principle based on the same technological concept. In connection with development and conception of various vehicle types the design of the guideways is standardized.

4.3.1 Structural Cross section of Guideway Beams

The guideway system consists of a steel reinforced plate box carrier, vertical supports, plate box, track and directional guide beams, as well as auxiliary equipment. The latter three components are bolted to the supports.

The auxiliary equipment consists of the power rail, reaction rail, interval measuring cable, and a carrier guard or outer plate (Figures 4-22 and 4-23). The supply cables to telephone and video monitors at the stations also run along the guideway. In addition, installations which are not part of the system, for example, pipelines for gas or water, could be installed within the guideway without significant increase in the crossectional dimensions.

The most important guideway element is the plate box carrier, which must be able to transfer the dynamic and static stresses of its own weight plus that of the traffic crossing over it to the beam supports. The carrier is of welded steel, hollow box construction (Figure 4-24); however, a compound construction is also possible (Figure 4-23).

The static characteristics of the steel guideway carriers have been evaluated considering both vertical and horizontal carrier vibrations (for example, caused by wind). For horizontal, vertical or axial bending of the carriers, the component steel paneled boxes are welded to each other at the appropriate angle. This forms a polygon of the appropriate radius (Figure 4-25).

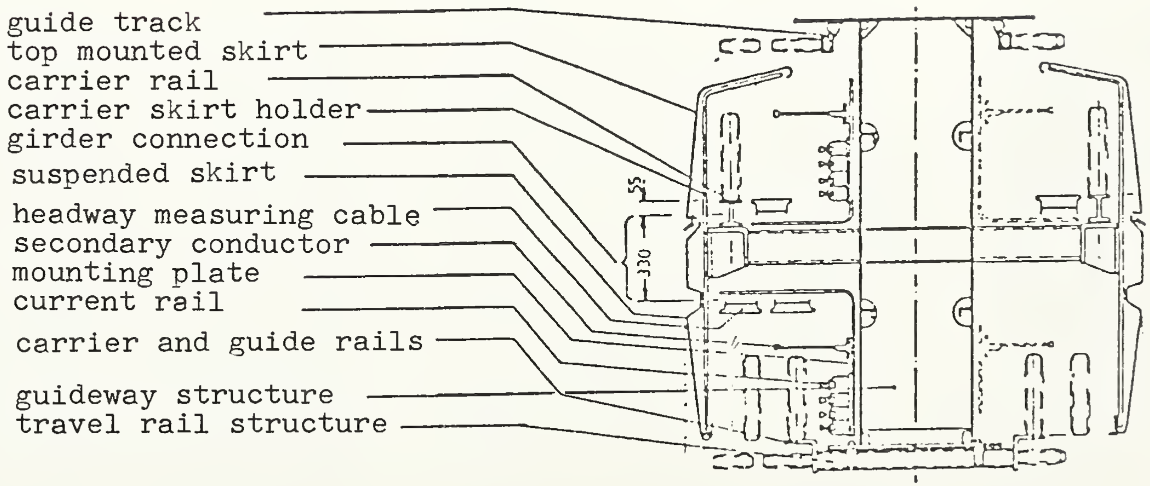


Figure 4-22. Cross Section of Guideway Beam

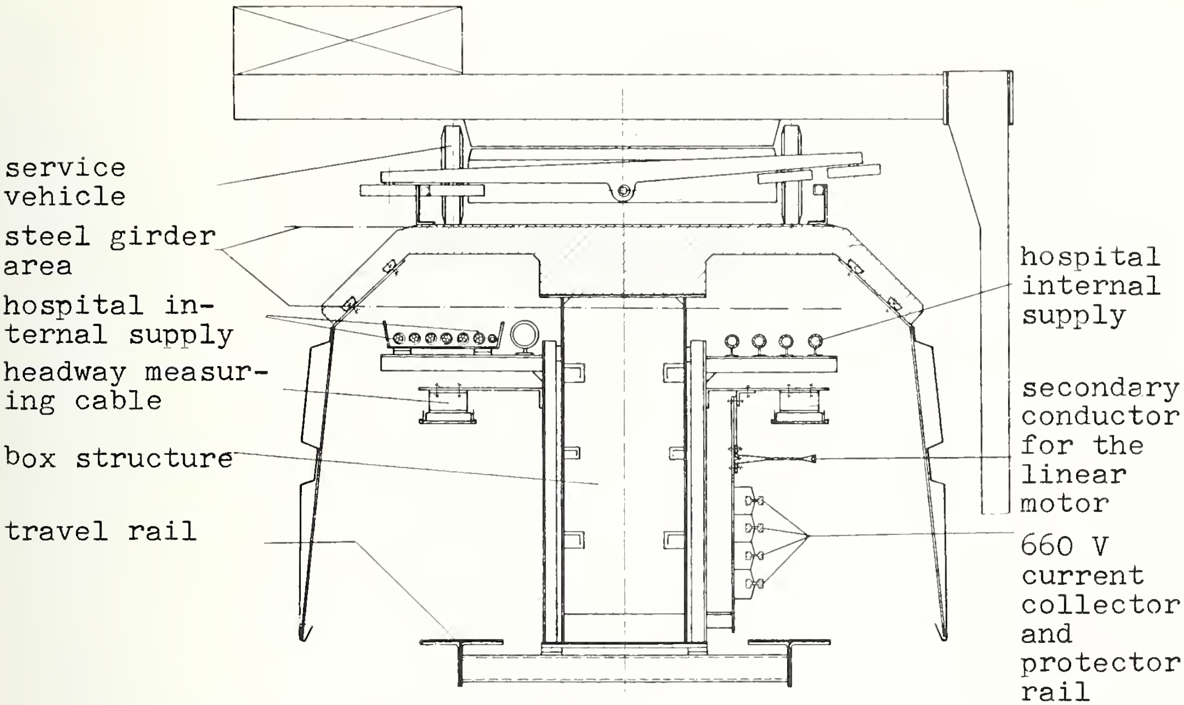


Figure 4-23. Cross-sectional View of Cabinlift Suspended Beam (first developed for the Cabinlift in Bremen)

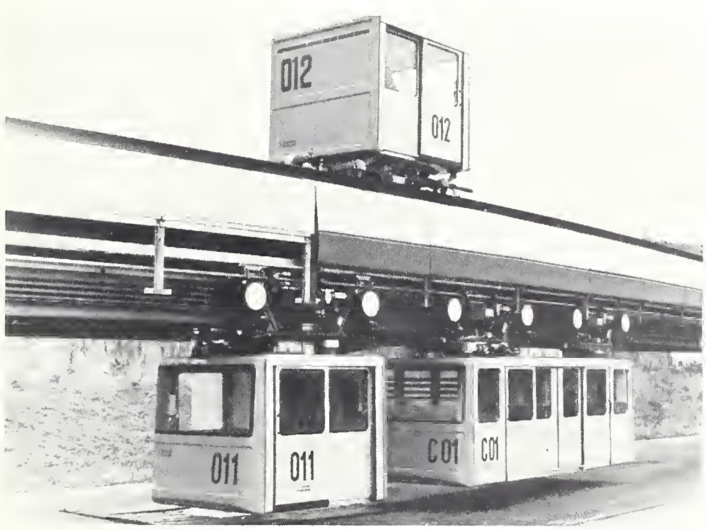


Figure 4-24. Guideway and Cabins at Test Facility in Hagen

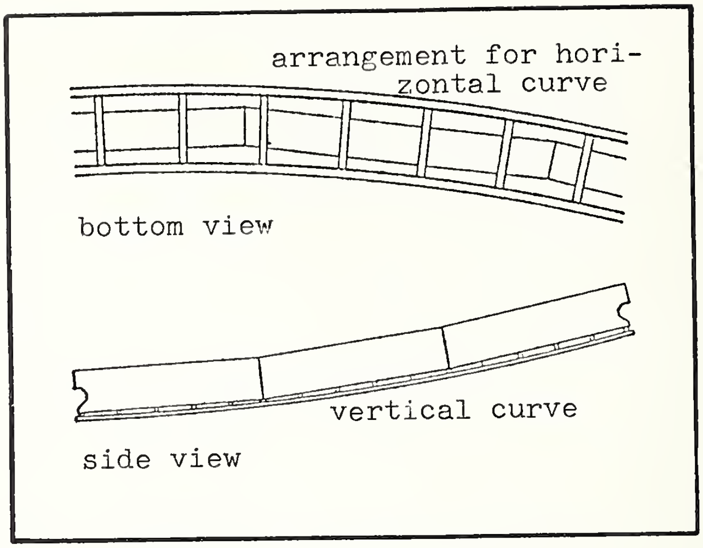


Figure 4-25. Bending of the Carriers

As protection against corrosion, either WT-Steel[1)] is used or a PVC- or latex-base coating is applied to the surface. Measures have been taken to damp the noise levels usually associated with this type of construction.

4.3.2 Tracks and Track Equipment

For carrier and steering guide rails, steel I, T, and L profile beams are used. Additional rails for steering and guidance by the switching wheels aboard the vehicles are installed in the switching sections (Section 4.4).

The tendency of a vehicle to accelerate radially in curves is compensated for by an active actuator on the vehicle or by banking of the track on the turns (Figure 4-26).

For riding comfort it is important that the abuttment points at the rail line up exactly. A connection, having as a component a special line-up guide, allows tracks to be fitted with an error in angle of less than 1 percent (Figure 4-27).

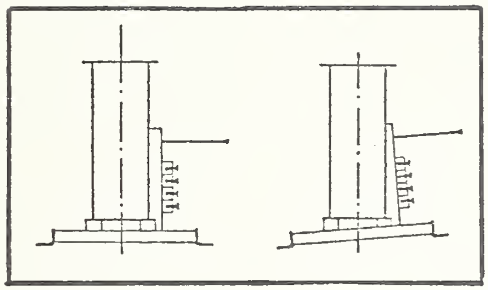


Figure 4-26. Design of the Carrier Rail to Compensate for Radial Acceleration (in turns) on the Suspended Guideway

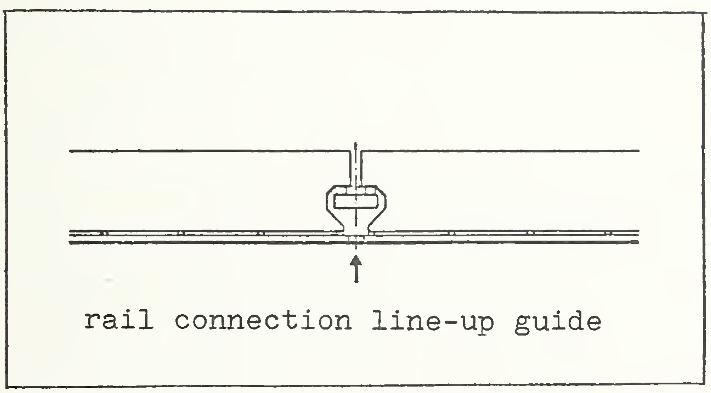


Figure 4-27. Carrier Rail Connection

1) For example, Cor - ten, Patinax

It is expected that there would be little wear on the carrier and guiderails due to the use of steel rails and all rubber wheels. However, bending or angles of the carrier or guide rails might require realignment after service of the carrier or guide rails. An aluminum panel fixed at 2.5 m intervals to the horizontal carrier with easily removable fasteners serves to damp the noise emission, as well as protect and improve the appearance of the exterior guideway. Installation and maintenance can be carried out after removal of this panel (skirt).

The carrier rails of the top-mounted track, the power rails, and the reaction rails are also fastened at intervals of 2.5 m. Power rails, reaction rails, and interval measuring cables are fastened to a mounting plate which is noise damped by a rubber/metal damping system.

High density traffic requires the largest possible conductor crossection for sufficient energy supply. Four parallel, double-T formed, full profile power rails are used. These are mounted on one side of the box carrier. This arrangement is well suited to the crossectional design of the box carrier. The technological aspects of the power rails are described in more detail in Section 4.8.

The reaction rail consists generally of 2.5 m long extruded aluminum sections (Al Mg Si 0.5), which is thicker on the exterior side. On grades of over 5 percent it is mounted on both sides of the box carrier.

The signal used for headway control between vehicles is transmitted along the interval measuring cable. The interval is determined by the strength of an AC signal, which is induced in the cable by the preceding vehicle. The interval measuring cable is a component of the signal rail assembly, consisting of an aluminum cover, ferrite rods, damping cable, and data transfer pickups. It is planned that the rail assembly would be installed redundantly in the top and suspended levels of guideway. In the switches and stations, however, redundancy is interrupted for short track sections. (For more information see Section 4.2.2.1.)

4.3.3 Guideway Supports and Support Foundations (Footings)

The supports are prefabricated of steel or concrete. According to the requirements of the guideway, different basic support forms are available (Figures 4-28 through 4-31):

- Cantilever supports for the plate box carrier; concrete or steel girder construction.
- A T-shaped support for the plate box carrier.
- A concrete mushroom support for the plate box carrier for the top mounted guideway.
- Pylons to support the plate box carrier for wide ranging cantilever construction.
- In special circumstances a goal post support with two vertical columns or a portal support could be used.

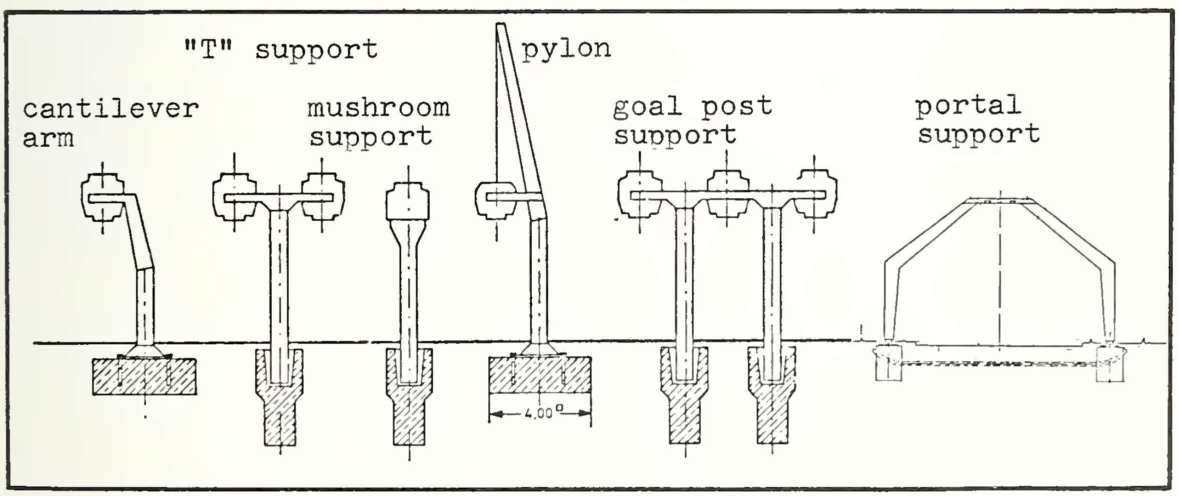


Figure 4-28. Guideway Supports

Figure 4-29. Guideway Supported and Suspended with Cantilevered Support

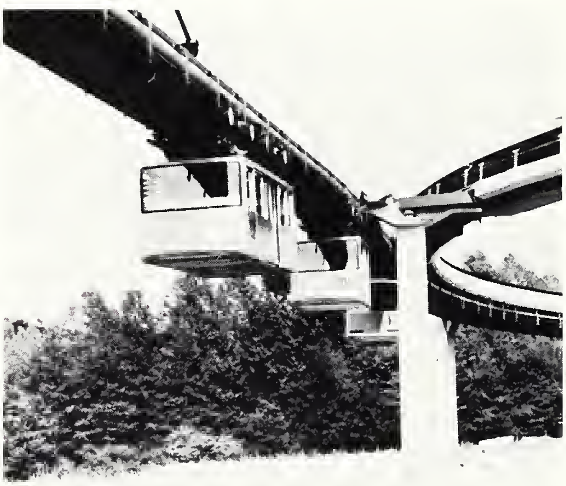


Figure 4-30. Cabintaxi Mixed Mode Operation

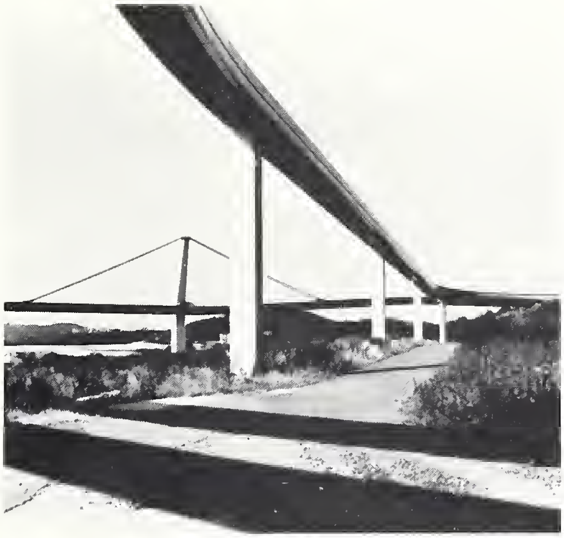


Figure 4-31. Pylon with Supported Guideway

Fastening of the supports to footings is dependent upon the type of footings and upon the sub-soil. If a large amount of settling is not expected, the upright design (Figure 4-32) would be preferred. In special situations a special doweled fastener may be used to advantage between the support and foundation. In specific cases (where the need for large adjustments may exist) anchor bars (dead man bar) with anchor screws could also be used.

A factory is envisioned for the prefabrication of supports, and possibly also foundation units. By having the components prefabricated the construction and assembly time at the building site is significantly shortened. Disruptions of normal traffic can be avoided to a great extent. For actual construction the only effort necessary is that required for keeping the guideway clear, for site preparation, for setting of the foundations and for the assembly of the various elements.

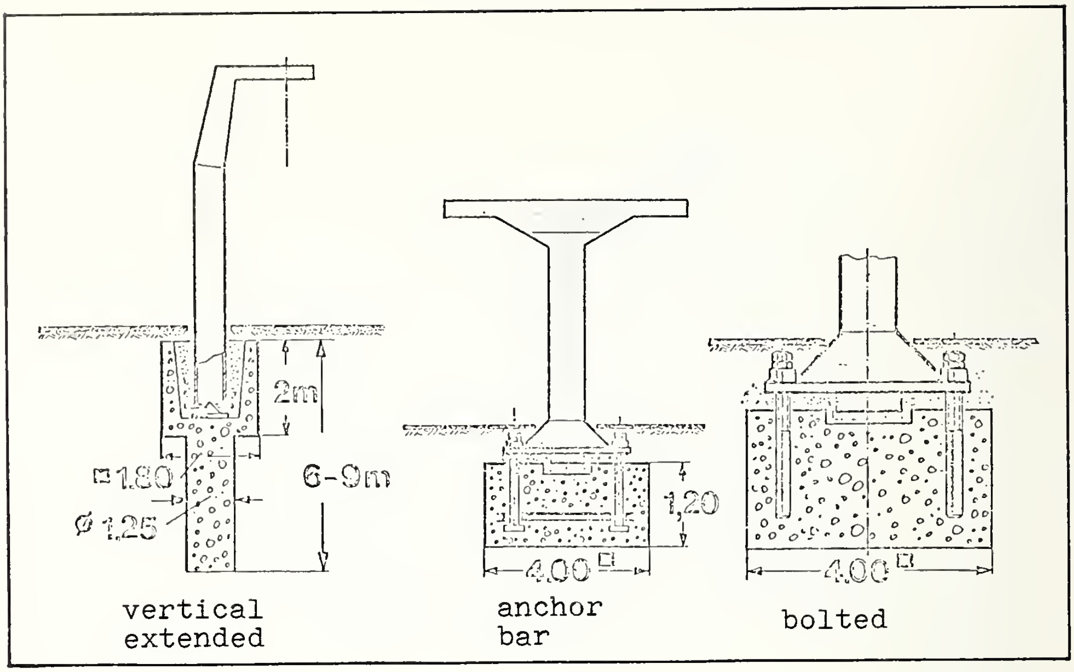


Figure 4-32. Design of the Footings or Foundations

The normal interval for the supports on a double guideway is 40 m for straight line track, and 30 m for curved track.

The adjustment of the supports is accomplished during the attachment to the foundations. The coarse and final adjustments of the plate box carrier are achieved within the overlap between the carrier and the support column.

4.3.4 Dimensions and Cross-sectional Views

Standard crossectional dimensions for the vehicles (Figure 4-33) as well as the guideway beam have been determined for the Cabintaxi and Cabinlift systems. In addition to the small crossection KK3 and KK12 vehicles currently on the test facility, larger crossection designs for large vehicles with stand-up places for passengers such as those in the Cabinlift are envisioned (Figure 4-34). The guideways can be built as single guideway (for suspended or top-mounted vehicles), as well as of composite construction (both together).

vehicle type	width m	small profile 1,4 / 1,0	middle profile 1 1,8 / 1,25	middle profile 2 2,0 / 1,4
KK 3 L = 2,0m 1,6	1.7	X seating only	(X)	
KK12 L-4,8m 1,6	1.7	X	(X)	
MK 12 2,4 3,6	2.0		X	(X)
	2.5		(X)	X
MK 25 2,4 5,6	2.0		X	(X)
	2.5		(X)	X

key : X = recommended combination
(X) = comb. possible but not always recomm.

Figure 4-33. Standard Guideway and Vehicle Dimensions

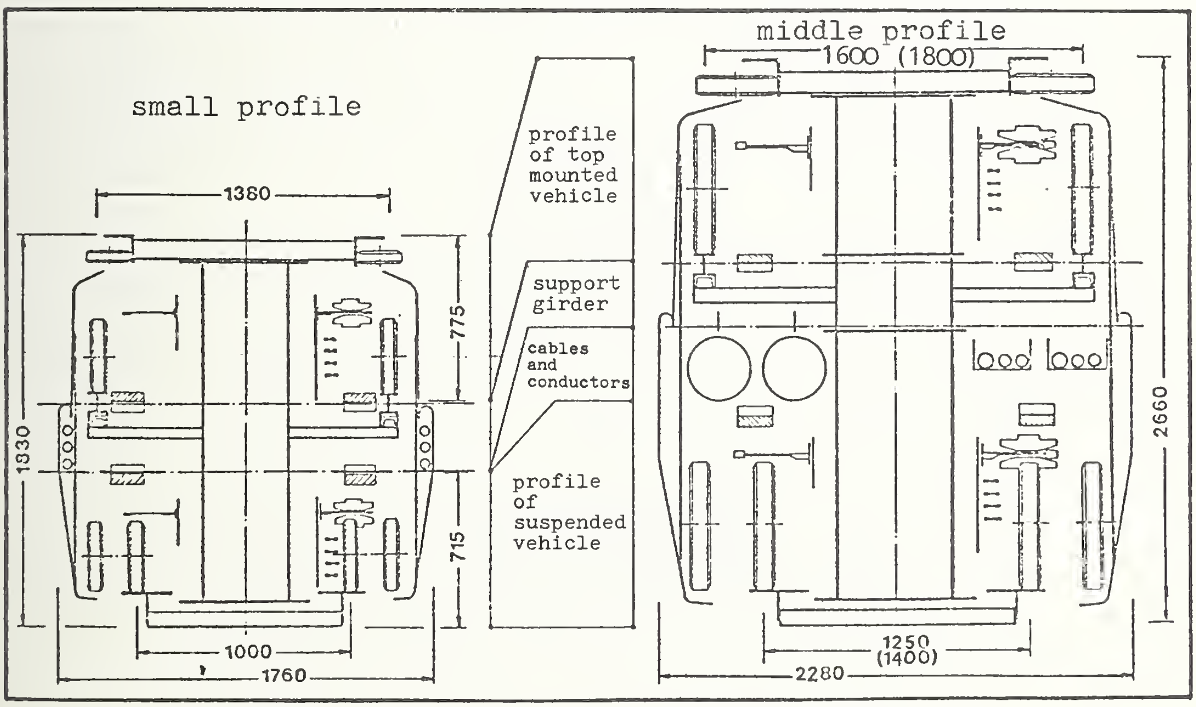


Figure 4-34. Standardized Double Guideway for Both Suspended and Supported Vehicles

The cross sectional views are presented in Figures 4-35 and 4-36 for the KK3 and KK12 vehicles.

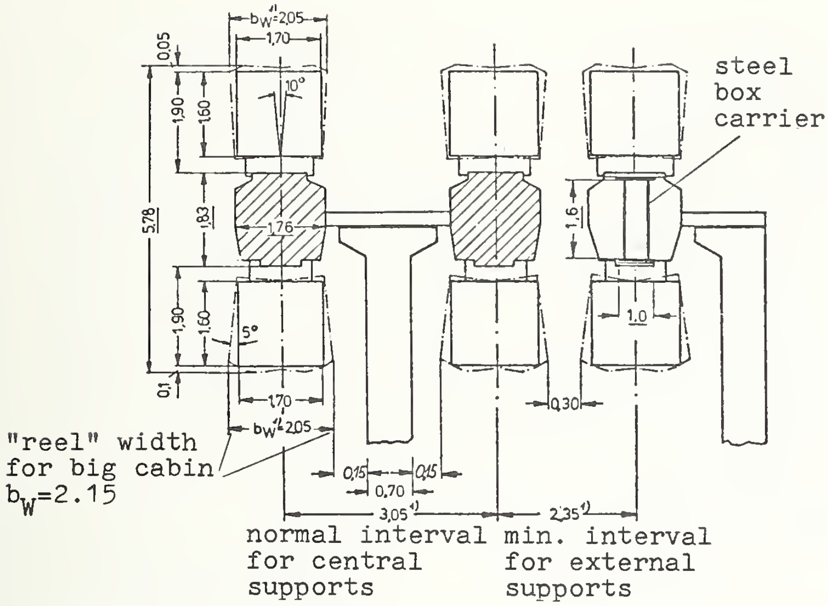
For construction of the Cabintaxi system (KK3 and KK12) both in its normal environment as well as in tunnels, a cross section was developed which conformed to the recommendations of BOStrab [6] (Figure 4-37). A safety margin of from 0.7 to 2.0 m is planned, which according to paragraph 13[7] of BOStrab, can be dispensed with in the elevated guideway design. The safety margin or interval between the limits of the vehicle and other structures (buildings, pylons, etc.) and the inter-vehicle interval is set at 0.15 m.

The required elevation of the guideway beam above the ground is presented in Figure 4-37 as follows: The bottom of the suspended vehivle must be more tha n 2.5 m above ground in the case of a pedestrian walk, 4.5 m above ground to allow other vehicles to pass under, and 0.5 m above ground for all other cases.

In a tunnel the vertical separation between the rails in either direction is achieved by having a two-story tunnel. The upper tunnel is for top mounted vehicles and the suspended vehicles hang from the concrete center deck. The tipping or swinging of the vehicles in both directions during turns has been considered.

The exterior measurements for the Cabintaxi system tunnel have been determined using the wall strength specified in reference [7]. In contrast to the conventional rail tunnel (Figure 4-38), the Cabintaxi Tunnel presents a slender vertical profile. The cross-sectional area is approximately 60 percent of that required for the conventional underground rail system.

A major advantage over the subway cross section is the need for less concrete and less excavation, which decreases costs. An easier accommodation of the narrow tunnel with min. 30 m radii curves into existing city architecture is therefore possible, and requires less purchase of private property.



1) dimensions for small cabin

Note: manufacturer reserves the right to change dimensions in the course of further development

Figure 4-35. Cross-sectional View of the Cabintaxi

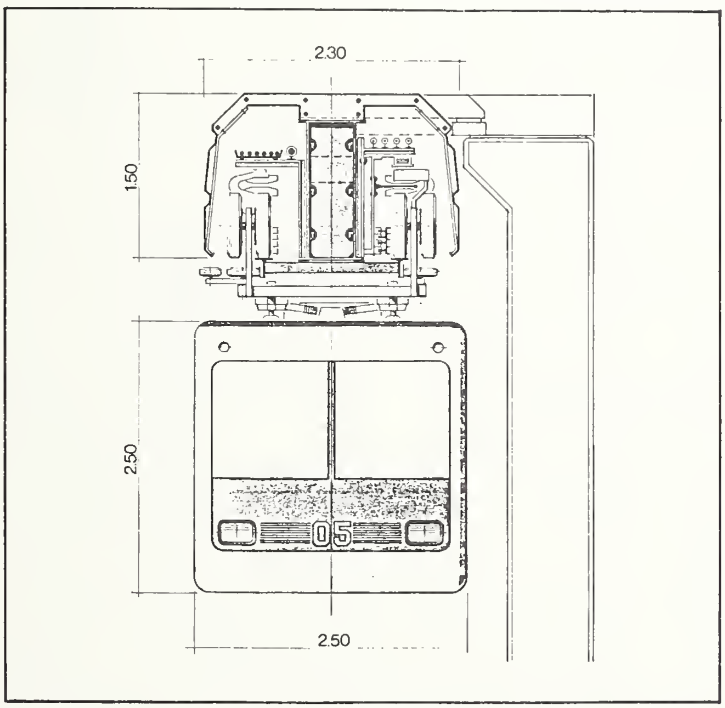
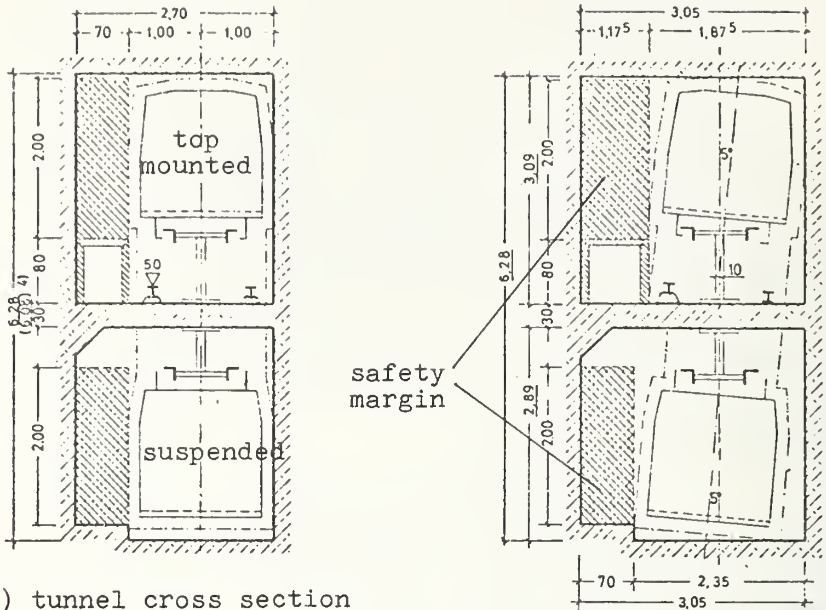
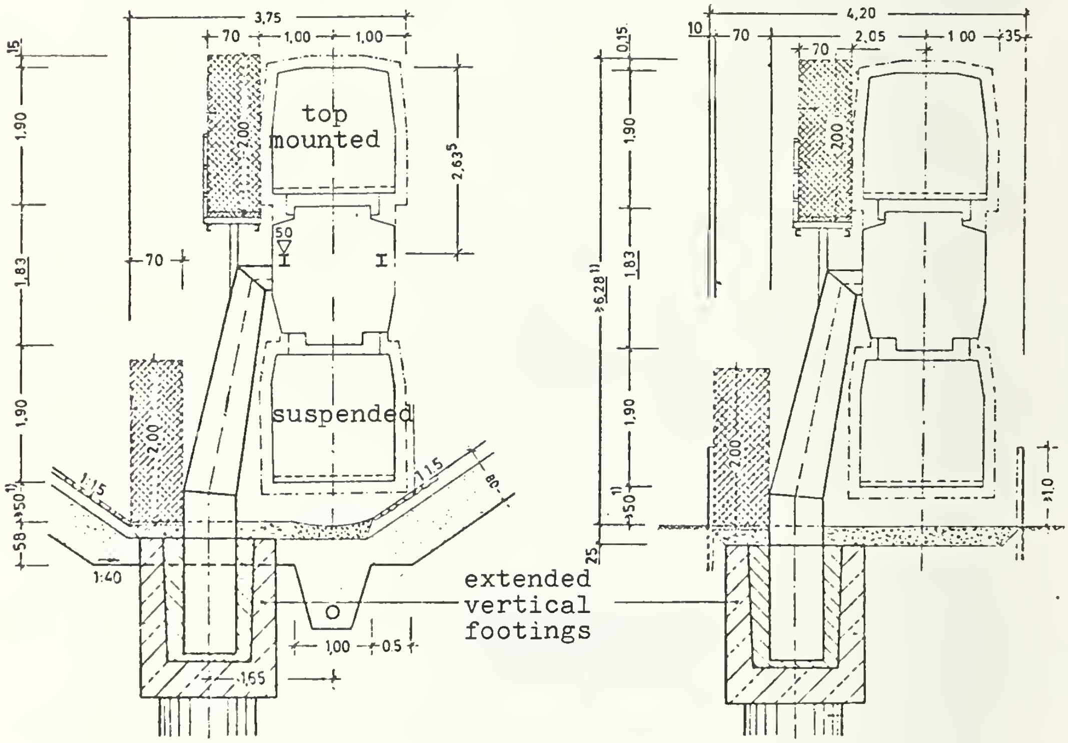


Figure 4-36. Cross-sectional View of the Cabinlift, Single Guideway for Suspended Vehicles



a) tunnel cross section (straight line track)

b) tunnel cross section on turns



c) cut (straight line track)

d) elevated

—·—·— the doted line represents the required boundary of the vehicle

Figure 4-37. Space Requirements

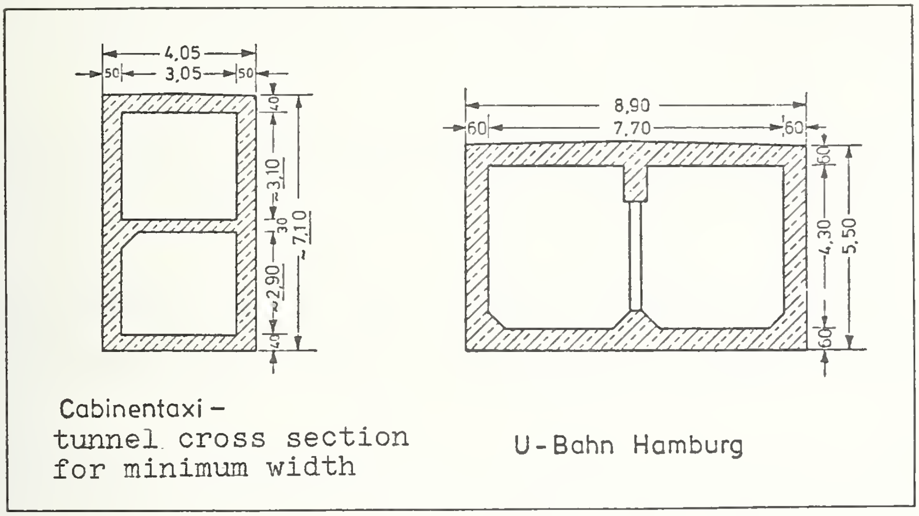


Figure 4-38. Comparison of Tunnel Cross Sections

A disadvantage to this design is the necessity for fairly deep excavations. In certain circumstances characteristics of the water table and geological strata must be considered.

4.3.5 Considerations Regarding the Layout of the Network

The layout of the guideway is basically determined by comfort, performance capability, dynamic limits placed on the vehicles, and the topography and structure of urban transport areas.

Cabintaxis and Cabinlifts have a closed form guidance arrangement, and because of the design of linear motors, do not depend on friction between the wheels and the rails for propulsion. Acceleration and braking limits can therefore exclusively be determined by the requirements of a comfortable ride.

Urban transport systems already in existence provide experience and information on the dynamic parameters required for passenger comfort. In deference to standing passengers, linear acceleration and deceleration is

normally held to between 0.9 and 1.5 m/s^2, with right-angle accelerations between 0.6 and 2.2 m/s^2. For planning and layout parameters of the Cabinlift, which is designed for standing passengers, values below this range (see Table 4-1) are provided.

For cabins designed only for seated passengers, these values are not binding. The ride characteristics in this case can be similar to those of a normal automobile.

The comfortable ranges for the 3- and 12-seat passenger cabins were determined by the manufacturer during tests with volunteers in an automobile, and later checked using visitors to the test facility.

For normal operation the following linear and centrifugal acceleration values have been considered as practicable:

$$\left.\begin{array}{l}\text{Linear acceleration} \\ b_x = 2.5 \text{ m/s}^2 \\ \text{linear deceleration} \\ b_x = 2.5 \text{ m/s}^2\end{array}\right) \quad \text{with } k_x = 2.5 \text{ to } 4.0 \text{ m/s}^3$$

Lateral acceleration (radial acceleration)
(Centrifugal acceleration):
$b_y = 2.5$ m/s^2 with $k_y = 1.6$ m/s^3

During the test program at the test facility, accelerations in the range up to 3.5 m/s^2 from a speed of from 0 to 15 m/s were investigated. According to the results, it can be expected that no acceleration, deceleration, or jerking motions will be encountered which are more severe than those experienced in a normal passenger car.

System layout parameters have been determined taking into account results of two project studies regarding the use of Cabintaxis in cities [8,9] (Table 4-1). The proposed speed of 10 m/s for the Cabintaxi vehicle and 6 m/s for the Cabinlift vehicle is possible even when using the minimum values recommended in this study.

Table 4-1

System Design and Layout Parameters

Design data	Symbol	Dim.	Cabintaxi 3 seats	Cabintaxi 12 seats	Cabinlift	Remarks
1. <u>Vehicle Data</u>			KK3	KK12	MK 18 (MK 1.5)	Manufacturers designation of the vehicles
1.1 Exterior dimensions length/width/height		m	2.3/1.7/ 1.6	4.8/1.7/ 1.6	3.94/2.44/ 2.40	
1.2 Seating places/ standing places		-	3/-	12/-	8/10	
1.3 Gauge width, top mounted/suspended		mm	1380/1000	1380/1000	1600/1250	
2. <u>Dynamic performance values</u>						
2.1 Proposed speed	v	m/s	10	10	6	Outside of the station area every operational speed is possible.
2.2 Ave. departure/ braking accelerations	b_x	m/s^2	2.5/2.5	2.5/2.5	0.6/0.6	Departure and braking accelerations are made possible by LIM propulsion which is independent of track to wheel friction.
2.3 Max. noncompensated radial acceleration	b_{ymax}	m/s^2	2.5	2.5	~0.6	Cabinlift value calculated with v, R_{min}, u_{max}
2.4 Max. jerk along axis of travel	k_{xmax}	m/s^3	2.25	2.25		
2.5 Max. right angle jerk	k_{ymax}	m/s^3	1.6	1.6		

Note: Parameters may change due to further development.

Table 4-1 (Cont)

Design data	Symbol	Dim.	Cabintaxi 3 seat	Cabintaxi 12 seat	Cabinlift	Remarks
2.6 Max radial sideway acceleration when stopping in curves		m/s^2	top-mounted 1.0 suspended -	top-mounted 1.0 suspended -	top-mounted ≈ 0.43 suspended -	Cabinlift: calculated with $\ddot{u}_{max}$ The tendency of the suspended cabin to lean decreases with decreasing speed until the cabin is vertical when stationary.
2.7 Max. vertical acceleration	b_{zmax}	m/s^2	1.0	1.0	0.125	Cabin lift: with H = 200 m H = vertical radius
3. Radii (horizontal projection)						
3.1 Smallest radius	R_{min}	m	30	30	30	Cabintaxi: with b_{ymax}, $\ddot{u}_{max}$ and v
3.2 Preferred radii	R	m	60 to 140 150 to 300	60 to 140 150 to 300		in 20 m increments in 50 m increments
3.3 Smallest tech. radius		m	16	16		for example, in vehicle storage facilities
3.4 Platform radius		m	no limit.	no limit.	Best radius R = 00	
3.5 Min. switching radius (branching radius)		m	40	40		
4. Connecting Track Sections						
4.1 Min. Spiral	A_{min}	m	25	25	25	Cabintaxi: with k_{ymax} and v

Note: Parameters may change due to further development.

Table 4-1 (Cont)

Design data	Symbol	Dim.	Cabintaxi 3 seat	Cabintaxi 12 seat	Cabinlift	Remarks
5. Max. Banking (vehicle incline to vertical)	$\ddot{u}_{max}$	$\measuredangle^{o}$	5	5		Vehicle incline (in turns) is accomplished by banking the track or by mechanical means aboard the vehicle. Under special consideration: top-mounted rail-hydraulic actuator; suspended rail-apparatus causing cabins to swing out on turns. The incline and length is appropriate to spiral length.
6. Bank ramp for top mounted guideway						Since only seating places are available the conventional limits of banking may be exceeded for the KK3 and KK12 cabins.
7. Longitudinal inclination						
7.1 Max. inclination	S_{max}	%	10.0 (proj. 15.0)	10.0 (proj. 15.0)	10.0	Propulsion and to some extent the brakes are independent from friction between wheels and rails. At s = 15.0 %, full acceleration and full speed cannot be reached.
7.2 Max. incline at stations	—	%	2.0	2.0	target 0	

Note: Parameters may change due to further development.

Table 4-1 (Cont)

Design data	Symbol	Dim.	Cabintaxi 3 seat	Cabintaxi 12 seat	Cabinlift	Remarks
8. Vertical roundoff, normal value	H	m	100/200	100/200	200 (150)	For Cabintaxi only: H=100 m for b_{zmax}.
9. Switch						Passive Switches curved switches are not planned. Vertical roundoff is to avoided since it involves special construction. "Spiral" is to be installed to prevent high jerk level conditions.
Min. branch track	R_{min}	m	40	40		
radius	A	m	25	25	25	
"Spiral"	a	m	24.5	25	20	
Minimal interval between conductor rails beginning and/or end		m	14-16	14-16		
Switch length from v-point to switch limit marker						
10. Intervals between supports						Should be determined using the determinant value. On switches the supports should be located as close to the branching point as possible. In spirals the support interval depends on the amount of bend. The spiral sections are welded together to the radius sections.
Straight line		m	40	40	40	
Curved, normal value		m	30	30	30	

Note: Parameters may change due to further development.

Table 4-1 (Cont)

Design data	Symbol	Dim.	Cabintaxi 3 seat	Cabintaxi 12 seat	Cabinlift	Remarks
Recommended radii	R	m	15 30 45 60	15 30 45 60		
Distance between supports		m	25 30 34 38	25 30 34 38		
			120>120	120>120		
			40 40	40 40		

Note: Parameters may change due to further development.

Basic dynamic performance values are listed in the Table. In comparison to the elements of conventional rail systems, the layout and design values are favorable and allow easy integration of the guideway into existing city architecture.

Modifications could result from the completion of the test facility or from the continuing development in this area.

Information concerning the minimum distance of the elevated guideway from buildings is expected as a result of the final planning review process for a demonstration system.

4.4 SWITCHES

Mechanically passive switches are used in the Cabintaxi/Cabinlift system. The active elements for determining the direction of travel are located in the bogie of the vehicle. Switch wheels are set to the required position, which will cause the vehicle to follow a guide rail in the appropriate direction (Section 4.5).

For this purpose additional guiderails are mounted in the switching sections (Figure 4-39). The switch wheels are set either right or left for demerging. For merging they are set to the outside of the switch (continuous rail).

The guide rails end after traveling past the switch, and the cabin is again guided along its course by the track following wheels. The vehicle can now receive a new directional command for the next branch. The time required for switching the guide wheels requires that the switches be at least 24.5 m apart (Figure 4-40) for the KK3 cabin.

To make sure of the positioning of the guide wheels, an additional guide rail is installed in the switching sections which is capable of mechanically displacing the guide wheels. To further assure safe switching the guide rails are overlapping in the switch section and the guide wheels are held in position by a bias spring. An electrical monitoring of the position of the guide wheel or switching wheel is planned (Section 4.9.6). Upon command from this monitor, controlled braking of the vehicle could take place in the event of switch failure.

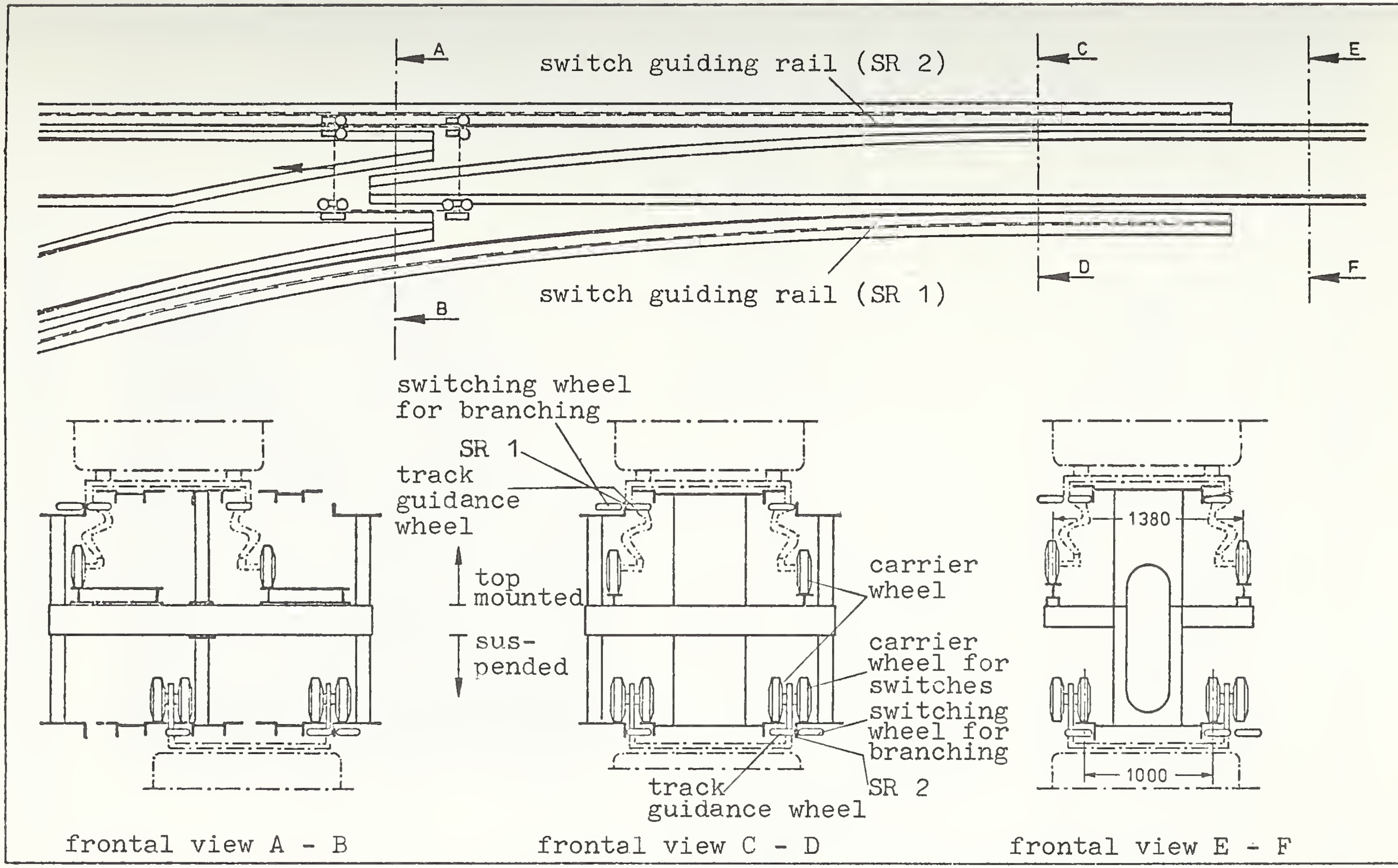
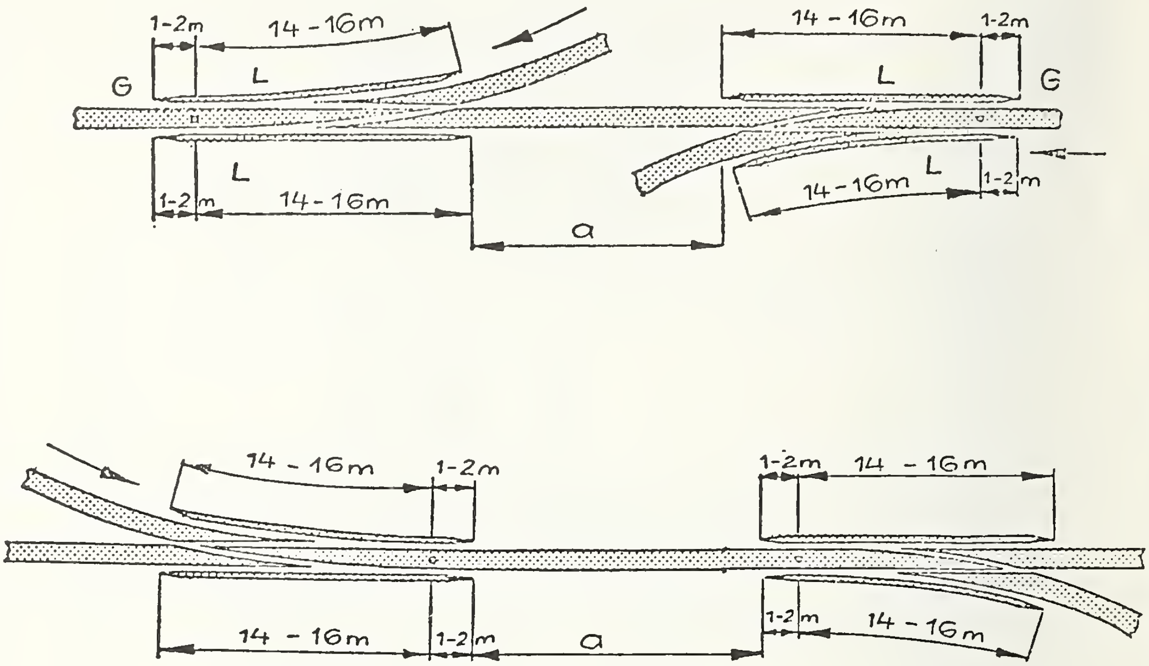


Figure 4-39. Track Guidance in the Switching Section



a ≥ 24,5 m	KK 3	10 m/s
a ≥ 27 m	KK 12	10 m/s
a ≥ 20 m	Cabinlift	6 m/s

L = switch guidance rail

a = interval between the end of the switch guidance rails of two consecutive switches

G = geometric branching point

Figure 4-40. Dimensions of the Merging and Demerging Switches for the Guideway

On each side of the suspended cabins an extra carrier wheel is fixed to the suspension to help carry the load in the switching sections. When traveling through the switch section the outside wheel runs on a specially fitted carrier rail. For the top-mounted cabins, double carrier wheels are not required. The vehicle traverses the switches in both directions on continual gapless rails.

The redundancy inherent in the design of the headway control system, voltage supply, linear induction motors, and linear induction brakes avoids any gaps in the function of these elements.

The geometric size of the switches has been determined with consideration given to the ride comfort requirements outlined in Section 4.35. The minimum double track radius is 40 m. To limit jerking spirals are installed, generally every 25 m. Switches should not be installed on curves or in a vertical radius since this requires special construction design.

Figure 4-41 illustrates a top mounted guideway switch and turn of min. radius as installed at the test facility in Hagen.

Figure 4-41. Top-Mounted Guideway Switch

The technical construction of the switch control will now be briefly discussed. A more detailed explanation is given in Section 4.2.2.3.

The control of the demerging switches is accomplished by a transmitter receiver unit which is installed in front of the switch on the guideway and connected with the station computer. A list is stored in the station computer with the proper directions to each destination, which can be reached from that switch and a related list which contains the appropriate "switch right" or "switch left" commands. The vehicle which has been loaded with the destination code (see Mission Logic, Section 4.2.2.2) before approaching the switch, transmits its destination address, and receives back from the switch the information necessary to set the steering or switching wheel.

Approaching the merging switch, a vehicle is mirrored as a virtual image into the other branch of the switch by a complex electrical installation involving the interval measuring cable. The interval measuring cables along the guideway approaching the switch are connected to the proper point in the other arm of the switch by a hard wired connection. These connections are made in 2 m segments to a distance of 60 m on each arm of the switch. The wires are laid along the interior of the guideway beam and cross over at the V-point in the switch.

During the first 30 m of the switch, i.e., the "soft virtual image range," the sequence of vehicles to enter the switch is determined by a control unit. Secondary vehicles are then transmitted the interval control signal from a primary vehicle. The signal is transmitted through a damping circuit in which the damping is reduced to 0 as the vehicle approaches the end of the "soft virtual image range".

Along the last 30 m before the V-point in the switch a hard virtual image range is initiated, whereby the signals are mirrored upon the other branch of the track via an amplifier circuit. Each vehicle influences the following vehicle in its position along the track regardless of which arm of the switch each vehicle is on.

4.5 VEHICLES

4.5.1 Vehicle Types

Several types of vehicles have been designed to perform different functions according to their size. Examples are the Cabintaxi vehicles KK3 and KK12, and the Cabinlift vehicles. These various sized vehicles can be used for the transport of personnel and also others are provided as work cabins (repair vehicles, etc.) and in the case of the Cabinlift, for cargo transport.

The Cabintaxi and Cabinlift vehicles, although designed for different applications, are based on the same technological concept. Subsystems, such as the passenger compartments, bogie (designs based on standardized track dimensions, Section 4.3.), liniear motors, etc. are based on a modular system, the elements of which can be used in the various vehicle types. In addition to the personnel and cargo transport cabins described below, operational work cabins are also being considered and/or in actual operation at the test facility. These will be discussed further in Section 4.8.5.

Cabintaxi KK3 and KK12

The KK3 and KK12 Cabintaxi vehicles illustrated in Figure 4-42 have been built for the test facility. Front and rear panels, doors, seats, and interior appointments are essentially identical in both vehicles.

Although the two vehicles offer 3- or 12- position seating, they have the same width and height measurements. In the 3-seat vehicle the passengers sit facing forward, in the 12-seat vehicle they sit facing each other (Figure 4-43).

Dimensions and Weights:

	KK3	KK12
Length	2.0 m	4.8 m
Width	1.7 m	1.7 m
Height	1.6 m	1.6 m
Empty weight (developmental target)	900 kg	2000 kg
Net loading (max.)	300 kg	1000 kg
Operational weight (max)	1200 kg	3000 kg

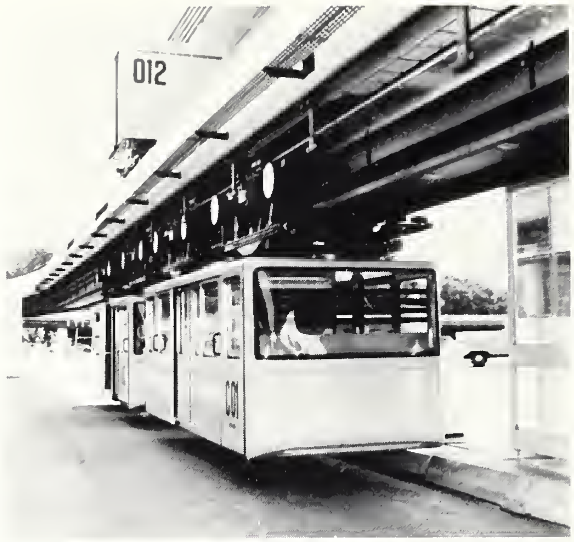


Figure 4-42. Cabintaxi KK3 and KK12

Both vehicles have similar ergonomic requirements. The vehicle floors and the platform have a height difference of about 15 cm. Therefore, when boarding the vehicle one must negotiate a step. The height of the cabin allows entry in a somewhat bent-over fashion similar to that used when entering an automobile.

The formation of trains is not envisioned for the KK3 cabins; however, the KK12 cabins might be coupled to form trains. Coupling does, however, raise problems of vehicle control. The mechanical parts necessary for vehicle coupling are already in existence at the test facility, while the electronic components for transfer of the control signals are presently under development.

Cabinlift

The Cabinlift vehicles have the same construction whether they are to be used for personnel or cargo transport within a work environment (hospitals, factories, etc.). A Cabinlift system is in operation in Ziegenhain, Germany, see Appendix A. Due to the height of the vehicle it is possible to stand up

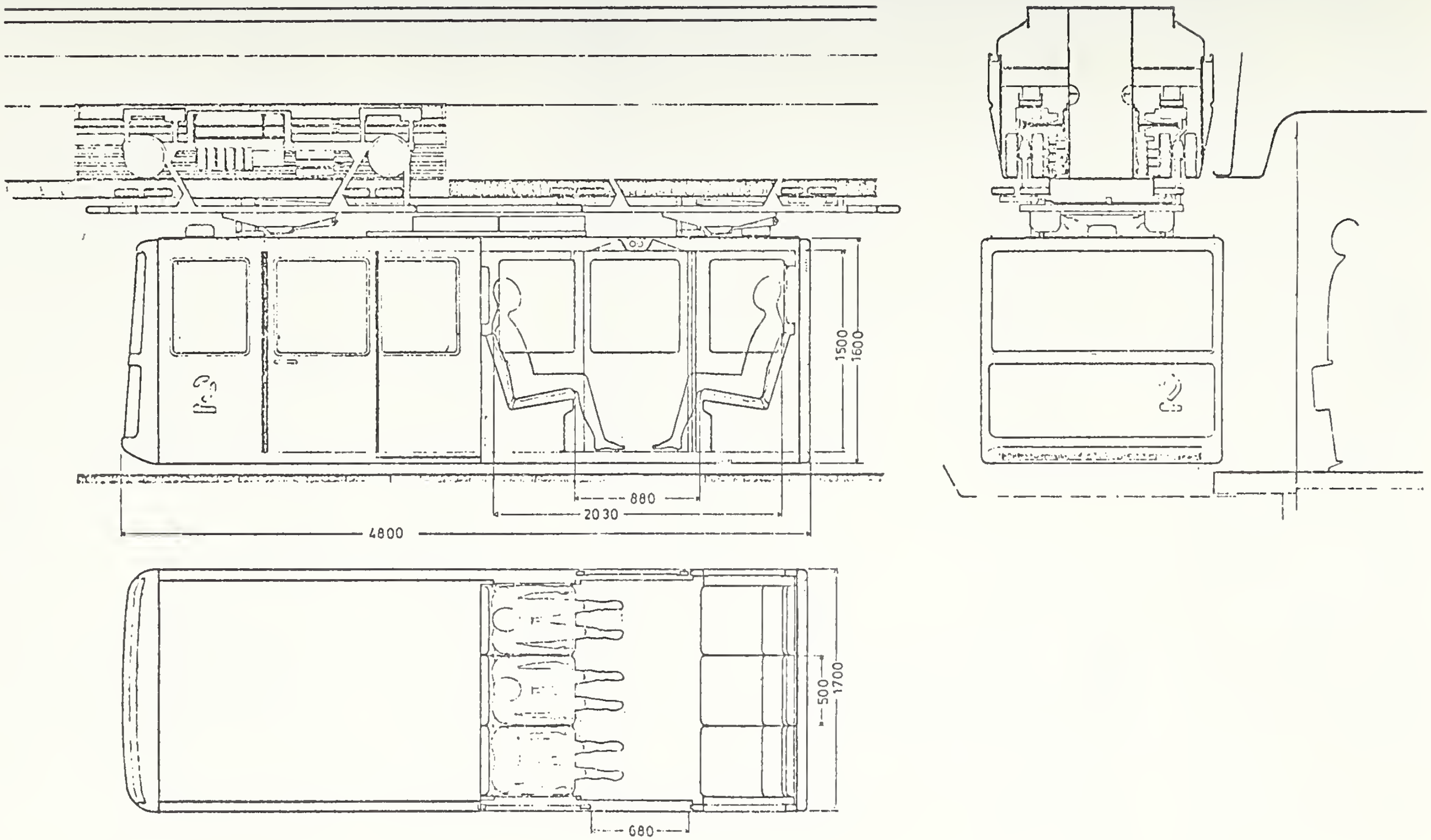


Figure 4-43. KK12 Cabintaxi (12 seats)

while riding. In the station, the Cabinlift has no level difference between the floor of the vehicle and the platform. Vehicle size and loading can be suited to the specific operational conditions.

Figure 4-44 illustrates the cabin vehicles as proposed in 1976 for a facility at the Medical Center in Boston [10]. Figure 4-45 shows the Bremen Cabinlift System which is presently in the detailed planning stages [12].

Dimension and Weights

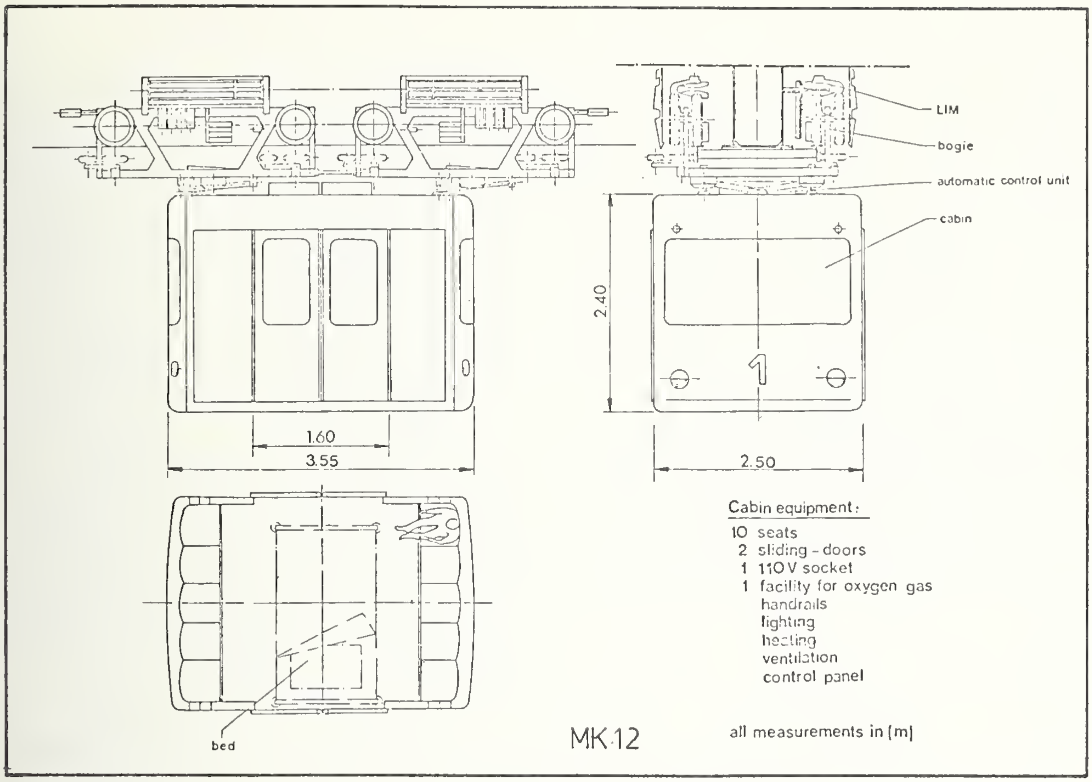
Designation	Mk 12 H	Mk 25 H	M 18 S
Measurement (m)			
length	3.55	5.6	3.94
width	2.5	2.5	2.44
height	2.4	2.4	2.40
Seats/standing places	10/2	14/11	8/10
Max. net weight (kg)	1,000	2,000	1,500
Gauge (mm)	1,400	1,400	1,600

Further conceptualization of the Cabinlift by the manufacturer (for the Mk 25/35/50 vehicles) shows that a large amount of standardization is possible (Figure 4-46). Cabinlift vehicles are being designed to carry from 12 to 50 persons.

4.5.2 Cabins

Each cabin is of light weight aluminum construction. The load-bearing cell structure consists of a welded frame with exterior paneling riveted in place.

"Spray cork" and "rock wool" are pressed between the outer plates for acoustical/thermal insulation. Much of the development is centered around stress testing and crash testing. Designs allowing easy fabrication for the interior cabin were also developed. It was attempted to use as many prefabricated and interchangeable interior components as possible among the different cabin types.



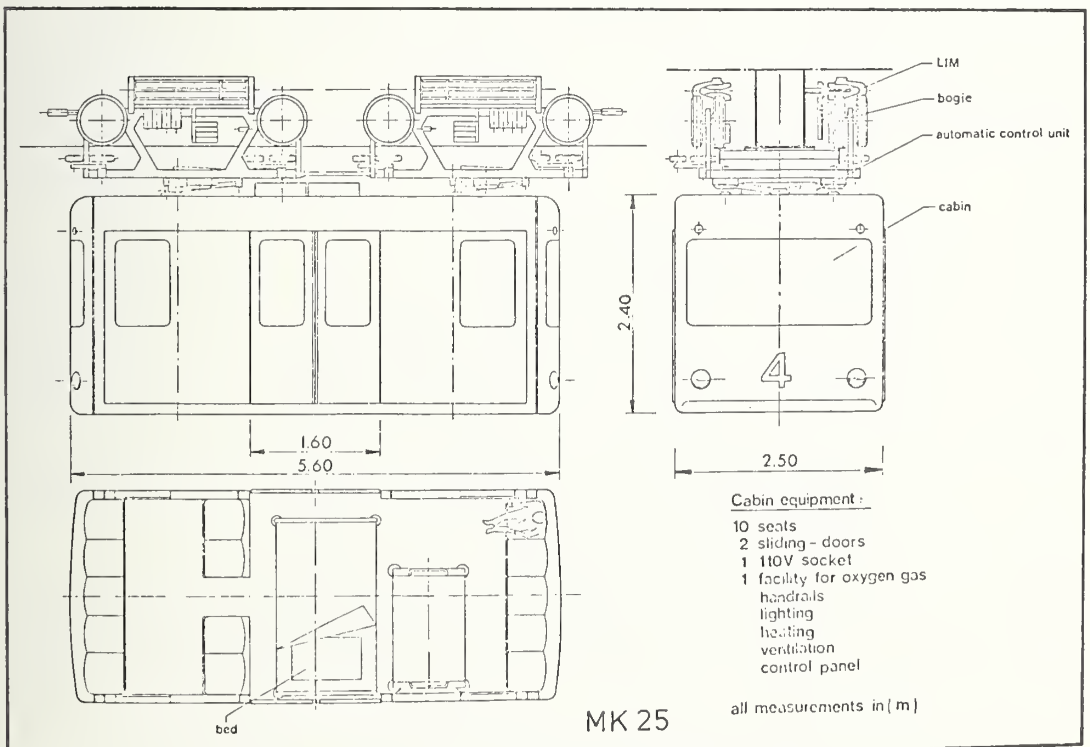


Figure 4-44. Cabinlift MK 12 and MK 25

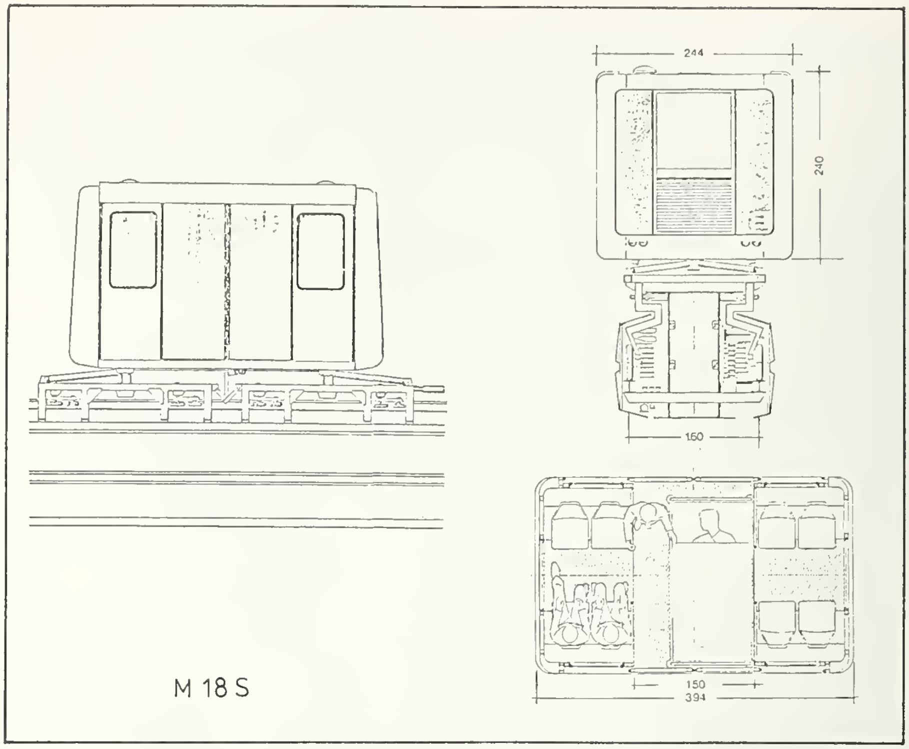


Figure 4-45. Vehicle for Cabinlift in Bremen

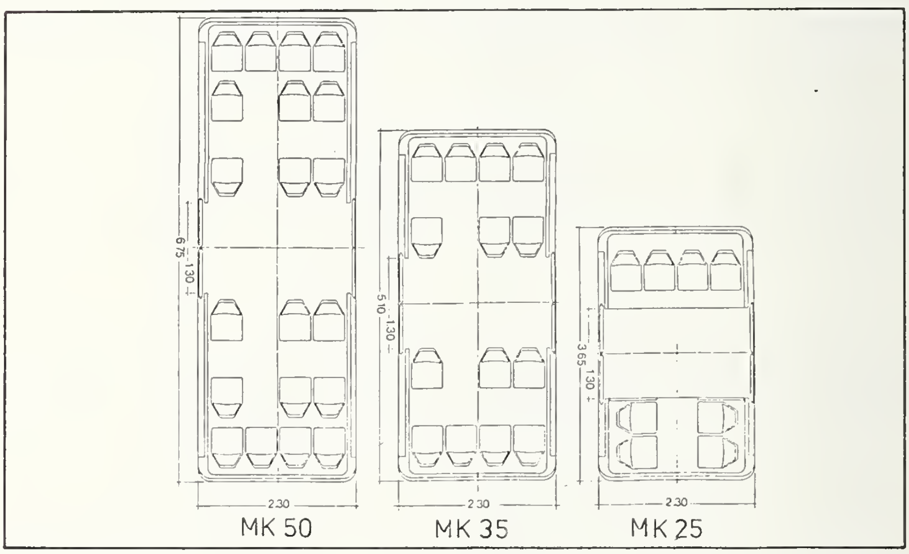


Figure 4-46. Additional Proposed Cabinlift Vehicles

The main compartments of the cabins are designed around a closed loop frame. The main cabin of the recovery vehicle at the Hagen test facility has lengthwise support beams to which the lateral carriers of the side wall post are welded. The front and rear panels of the small cabin KK3 and KK12 are made of fiberglass.

Wall, ceiling, and floor areas are insulated against noise and heat loss with "spray cork" and "rock wool".

To protect the passengers from serious injury in a collision, the front panel is made of composite safety glass and equipped with a crash pad. Crash testing is used to check the efficiency of this arrangement and its interaction with the entire cabin. The side windows of the cabin are made of single-sheet safety glass.

The KK3 and KK12 cabins at the test facility are equipped with manual doors, except one KK3 vehicle is equipped with automatic doors.

The manually opened accordion doors in the KK3 and KK12 vehicles open to a width of 0.68 m. Their closing point is in the center of the vehicle wall. The door panels are damped toward the end of their closing cycle by a combined damping/door closing unit, then slowly pushed into the closed door position.

Automatic doors such as those found in elevators have been used in the Cabinlift design. The opening width in each case is more than 0.8 m. The vehicle control unit prohibits the departure of the vehicle when the door is open, or the opening of a vehicle door along a clear track section.

The Cabintaxi vehicle is designed exclusively for seated passengers. The height of the cabin, therefore, is only 140 cm (Figure 4-47).

Formed shells of reinforced fiberglass or upholstered seats are used for passenger seating. The design has attempted to assure that passengers, and especially older people may comfortably stand up and leave them, and not slip off during emergency braking. The use of passive safety systems such as air bags and seat belts are being investigated. (see Section 6.8).

Figure 4-47. Interior View

The operational controls for the KK3 and KK12 vehicles are located in the ceiling and are easily reached by the passengers. Baby carriages, as well as other cargo such as skis, can also fit into the cabins.

Standee places are available in the Cabinlift vehicles since they have an interior height of 2.10 m. The transportation of various types of cargo is possible because of the large door opening width.

Fireproof and easy to care for materials are used for the Cabintaxi and Cabinlift vehicles. The cabins can be equipped with an intercom system (e.g. Cabinlift, Ziegenhain in Appendix A).

The vehicles are heated with thermostatically controlled forced air heaters. In winter the warmed cabin air is recirculated and only the required amount of fresh air is allowed into the cabin. The fresh air to recirculated air ratio is determined by an adjustable vent flap for summer and winter operation.

Ventilation during summer operation is accomplished by the normal heating fans with the heating elements turned off.

A heating power of 3 kW is planned for the KK3 cabin, and 6 kW for the KK12. The heating is protected behind a perforated plate. The heating element consists of covered heating bars. Passengers cannot be burned or otherwise injured by coming in contact with these heat bars.

Air conditioning as standard equipment is not being considered for the Cabinrail system.

4.5.3 Bogie

The various cabins are fitted with bogies having similar technological principles. The KK3 cabin is fitted with a single bogie, whereas the larger KK12 Cabintaxi and Cabinlift vehicles have two bogies. The bogie is the exterior running type, that is, it spans the crossection of the carrier (Figure 4-48).

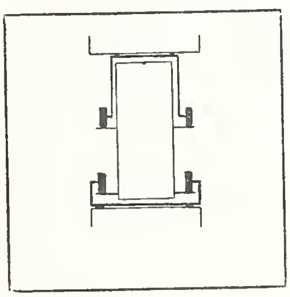


Figure 4-48. Exterior Running Bogie

Each bogie is equipped with solid rubber tires. These tires run on two steel rails, and the suspended cabin has a twin set in order to negotiate the V-point in the switches. Four additional wheels are horizontally mounted as guide wheels and run along on horizontally mounted rails (Figure 4-49). Because rubber tires are used, direct noise radiation from the point where the running wheels contact the rail is relatively small.

For control at the switches, the bogie is equipped with additional horizontal switching wheels for directional guidance.

The carrier wheels are made of an aluminum core with a solid rubber covering. If track and guideway adjustments are correct the tires can run up to 40,000 km. Further development is aimed at developing tires which will serve a year in operation and run about 60,000 vehicle km. Balancing of the wear is possible within limited ranges by readjusting the wheel suspension (Figure 4-50). High amounts of tire wear lead to problems with the power rail, and endanger the minimum distance required between the primary and secondary sections of the linear induction motor and brake.

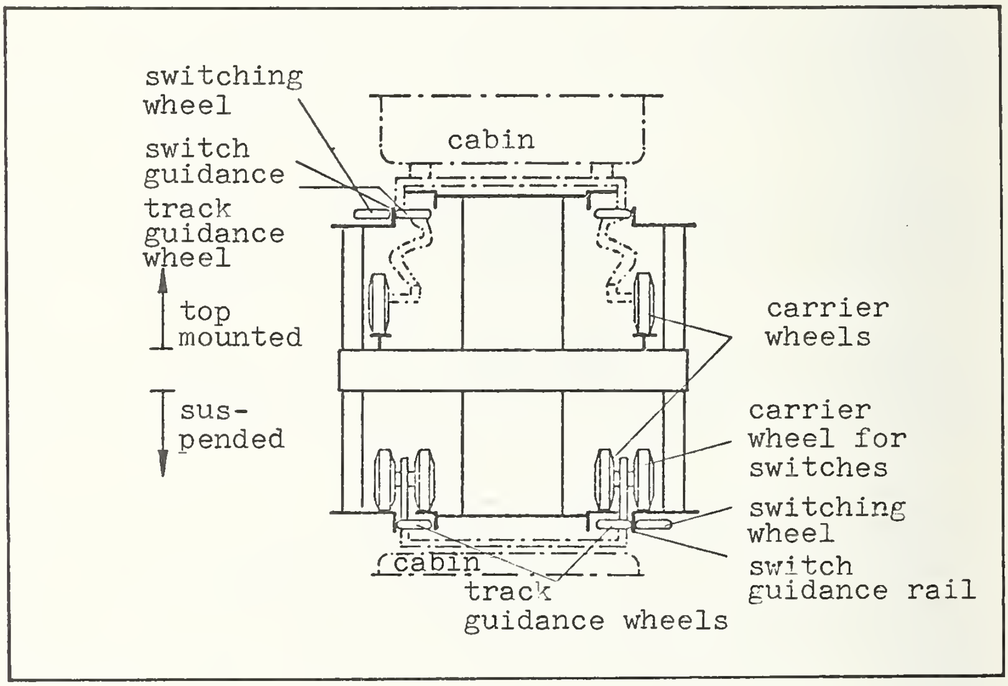


Figure 4-49. Track Guidance Elements in the Switch

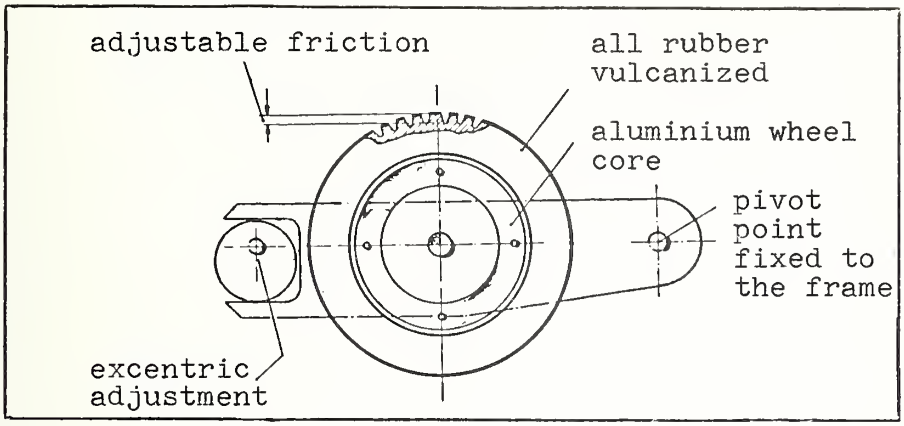


Figure 4-50. Carrier Wheel and Mounting Assembly

The Cabintaxi vehicle KK3/12 is equipped with 300 mm radius wheels (wheels of 340 mm radius have also been tested). The larger vehicles have been designed to use 460 mm wheels. The wheels have no function in the propulsion of the vehicle, but do provide some braking torque.

Track guidance is accomplished in sections other than the fixed switching sections by four horizontal guide wheels mounted on either side of each bogie assembly. In a switching section, the appropriate switching wheel swings outward (Figure 4-51) and is captured by a fixed guide rail in the guideway (see Section 4.4).

The switching wheels are connected to one another with a fixed bar to assure that only one engages the guide rail. The switching wheels at the present time are activated by both an electric polysolenoid push rod and a hydraulic apparatus. This system is currently under test. No significant wear takes place on the track guide elements.

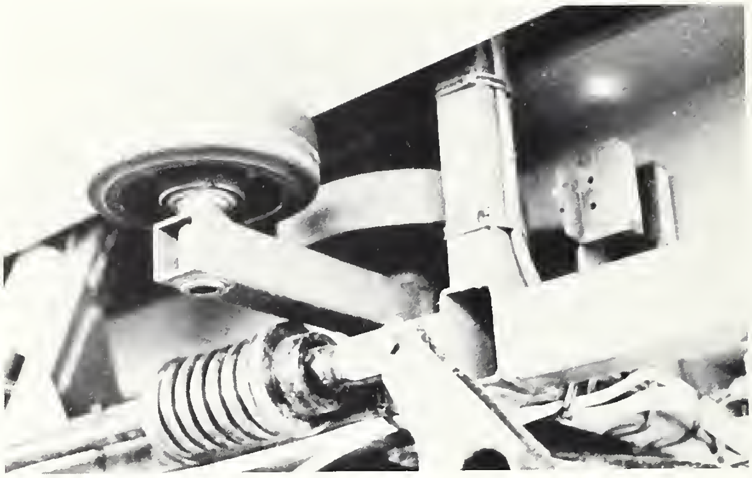


Figure 4-51. Bogie with Switching Wheel

Various systems have been utilized for cabin suspension. On several of the vehicles the bogie and cabin are suspended by means of a spring steel arm fastened at both ends with universal joints providing a spring action in both horizontal and vertical directions (Figure 4-52). In addition, a suspension system designed by the Porsche firm has been in testing since 1976. Hydropneumatic suspension systems are also being tested. The KK12 cabin at the EPA (Hagen test track facility) is vertically suspended using compressor-less air springs which have a damper and in the horizontal direction by a three-leg arrangement of springs.

The cabin can be set to the desired angle for negotiating curves by elevation of the outside track; this system is presently used at the EPA (Section 4.3). The suspended system has a device for damping of cabin oscillations, i.e., lateral swinging. A hydraulic pitch activating system is being tested for the top-mounted vehicles.

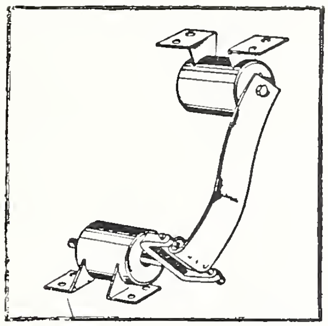


Figure 4-52. Bogie Suspension

A safety system to prevent overloading of the vehicles, especially the Cabinlift vehicles, is currently under development and will be installed in the bogie. An optical or acoustical signal will indicate when the maximum load has been exceeded. The cabin will not leave in the overloaded condition. The Ziegenhain Cabinlift (which is already in service) is equipped with such a system (see Appendix A).

The power collectors (Figure 4-53) are located on either side of the vehicle. For negotiating switches and branch points, the power collectors are used alternately. Each power collector is redundant with two separate sliding contacts. The originally targeted useful life of the contacts of 50,000 km has apparently been significantly exceeded according to results from test runs.

4.5.4 Propulsion and Braking

The active components of the asynchronous linear motors (LIM) are mounted outside of the main cabin in the bogie. This arrangement has

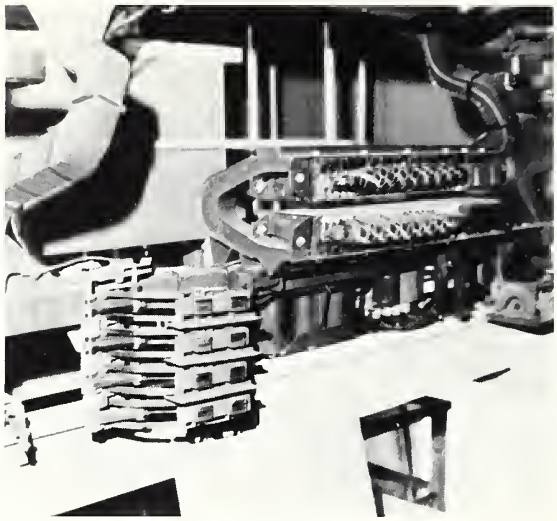


Figure 4-53. Power Collector

advantages for maintenance purposes. Since this drive system has no moving parts, the propulsion system is basically wear free, and therefore does not require much maintenance.

Propulsion is independent of the contact between wheels and support rails since the pushing force is accomplished electromagnetically without contact. Tire wear can therefore be held to a minimum and is not significantly influenced by inclement weather. This type of propulsion allows high beginning acceleration as well as high braking decelerations. Acceleration and deceleration values are limited only by the ride comfort of the passengers. In addition, large grades of up to 15 percent can be negotiated, making use of the system in hilly areas possible. Conventional rotary motor drives have limits in this respect.

A linear motor (linear induction motor, LIM) may be thought of as a sliced open, parallel, synchronous, or asynchronous motor, the stator of which has been cut and laid out in a linear form (See Figure 4-54).

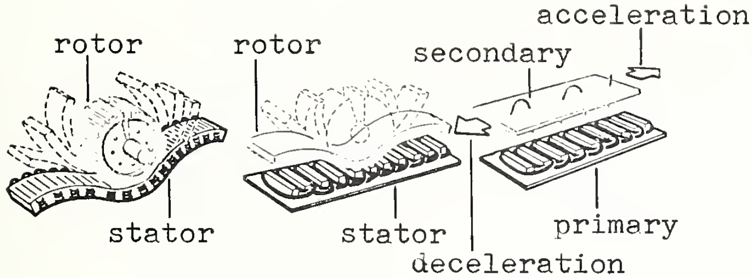


Figure 4-54. Principles of the Single
Sided Linear Motor Ref. [15]

Instead of an AC field, a traveling field is created. The winding cage in the motor (secondary windings) are replaced as secondaries by the reaction rail. This arrangement has two options:

1) The current carrying primary component is located on the guideway. This is called a "short running motor".
2) The current carrying primary component is located on the vehicle. This is called a "short standing motor".

The "short standing motor" was chosen for the Cabintaxi/Cabinlift system. Each vehicle has two horizontally mounted asynchronous double-sided linear motors. They are located on either side of the bogie and run exterior to the guideway beam. This arrangement is necessary for negotiating the fixed switches (Figure 4-55).

Figure 4-55. Propulsion of the Cabintaxi

Control of the propulsion force is accomplished by a phase control unit in the vehicle's AC current supply. This control concept satisfies most of the requirements, and in addition has the advantage of simplicity of implementation. This circuit arrangement has two disadvantages for larger networks:

- Feedback effects into the main power supply due to harmonic current oscillations
- Large reactive power requirements

These disadvantages can be reduced by the use of filters and reactive power compensation equipment.

Linear motor control by means of a frequency converter instead of phase control is currently under investigation. A frequency converter using a successive phase extinction process with an intermediate DC circuit appears possible and should allow almost loss-free speed regulation, as well as

effective braking. At low speeds, loss in the secondary circuit is relatively high due to the phase section control. The efficiency decreases in a linear fashion with respect to speed reduction. The use of a frequency converter in this application because of its small secondary power loss would be advantageous. At 10 m/s the effective power consumption of both methods is approximately the same. At high accelerations and speeds the frequency converter is less efficient than the phase control unit. At motor frequencies of higher than 50 Hz, the secondary loss of the frequency converter increases with respect to that of the phase control configuration. If the Cabintaxi is to be operated at high accelerations and high speeds then the phase control version may be the more suitable of the two.

For acceleration and braking the linear motor uses a controllable rectifier in a 3-phase bridge circuit. Braking is accomplished at high speeds electrically by the linear brakes, at lower speeds by mechanical wheel drum brakes which also serve to increase emergency braking ability, as well as stopping from slow speed and holding brakes. For emergency braking the two types of brakes work simultaneously. When the vehicle is stationary or in case of emergency, the wheel brakes are activated by springs.

	Units	Cabintaxi	Cabinlift	
		KK3, KK12	1)	2)
Acceleration	m/s^2	2.5	0.35	1.0 (0.8)
Speed	m/s^2	10	7/10/15	
Deceleration	m/s^2	2.5	0.35	1.0
Emergency braking deceleration	m/s^2	5.0	1.5	2.5
Max. deceleration electrical/mech./ total	m/s^2	3.0/3.5/6.5	-	-

1) Cabinlift for hospital facility; acceleration and deceleration are limited for the transport of soup, for example at the Ziegenhain or Bremen facility

2) Cabinlift which does not transport food; acceleration and deceleration values adjusted for standing passengers

The two-sided LIM consists of two simple single-sided LIMs. The primary component then consists of these two opposed LIM halfs between which the reaction rail is mounted as the secondary component (Figure 4-56).

The air gap has a large influence on the energy use and is about ±6 mm. The energy use of the 3-seat cabin is about 0.3 kWh/vehicle at a speed of 10 m/s.

The manufacturer has fabricated two types of linear motors; one for a max. of 8 m/s (Ziegenhain Cabinlift), and the other for a max. of 12 m/s for the Cabintaxi at the EPA. Since June of 1977 a motor with a max. speed of 16 m/s has been in test. To save energy, operational speed is aimed at somewhat less than maximum speed (Cabinlift, 6 m/s, Cabintaxi, 10 m/s). Energy use of the propulsion system is expected to be decreased by about 20% percent through further development.

Tests are presently being conducted at the EPA with cabins having rotation motors for their propulsion. Under normal operational requirements, that is, in the absence of extreme grades, rotating motors (DC motors) similar to those used in present urban transport vehicles could be used. These propulsion motors work through gearing to operate carrier wheels which would act also as drive wheels in the bogie.

Compared with linear motors, rotating motors offer a higher efficiency with a significantly less reactive power requirement. The specific horse power to weight ratio of rotating motors, including their gearing, is more favorable.

A further option is the use of three-phase motors. Speed regulation would than be accomplished by means of a frequency converter.

4.5.5 Control Elements

In addition to measurement and regulation equipment, vehicles are equipped with various elements for communication. These are discussed in Section 4.2.2 and will be noted briefly here. For headway control, the

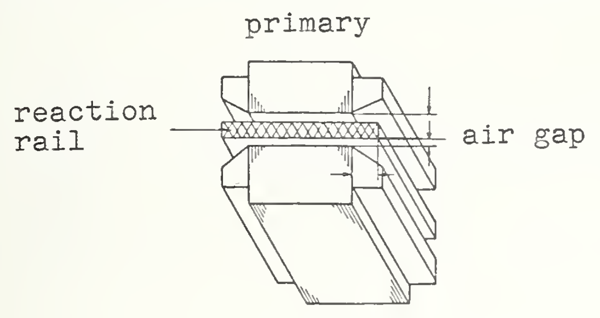


Figure 4-56. Principle of the Two-Sided LIM

vehicles are equipped with two tachometers for speed determination. Transmitter, receiver, and compensation transmitters are mounted on either side of the vehicle, comprising a redundant system. Data transfer monitoring and the installation of an additional headway control system have been proposed.

The headway control system is connected with a drive regulation unit of the vehicle. Mission logic is used for the storage and transfer of data including the destination code and for status information related to switching operations and the determination of the various types of track sections.

The power supply for the control system is 24 V. A buffer battery assures that the controls of the emergency braking systems are always in operational readiness. Analogue electronics are powered by a ±15 V supply.

4.6 STATIONS

The type of station which is to be used for each system is determined by the planned operational strategy. Off-line stations, for example, will be used for the discretionary, discretional transport mode of the KK3 cabin.

The KK12 and Cabinlifts could use either on-line or off-line stations, depending on the circumstances and conceptual layout of the system. The station equipment depends on the type of operation planned. If an individualized operation is planned, then the appropriate platform design must be considered (for example consideration should be given to an area where passengers can line-up and place their belongings on the platform in front of the docking point).

The Cabinlift stations may need special facilities. For example, a hospital facility might need additional freight transport.

Standardized prefabricated elements are being considered for the station to save construction time.

4.6.1 Off-line Stations

At an off-line station the vehicle is branched from the main guideway onto a parallel guideway where it stops to allow boarding and de boarding. The vehicle then accelerates, merges with the main guideway, and enters the regular traffic flow.

Three arrangements of boarding platforms for off-line stations are shown in Figure 4-57. An off-line station design is shown in Figure 4-58.

CALCULATION FOR OFF-LINE TRACK LENGTH

The length of the off-line guideway is to be calculated as illustrated in Figure 4-59.

If cabins are to be coupled into trains, then the the train length should be substituted for d_o.

For the Cabinlift, no values are available for the length of x_A.

A length of 84 m is required for the demerging, braking and accelerating of an off-line guideway for the Cabintaxi system. The length of the boarding

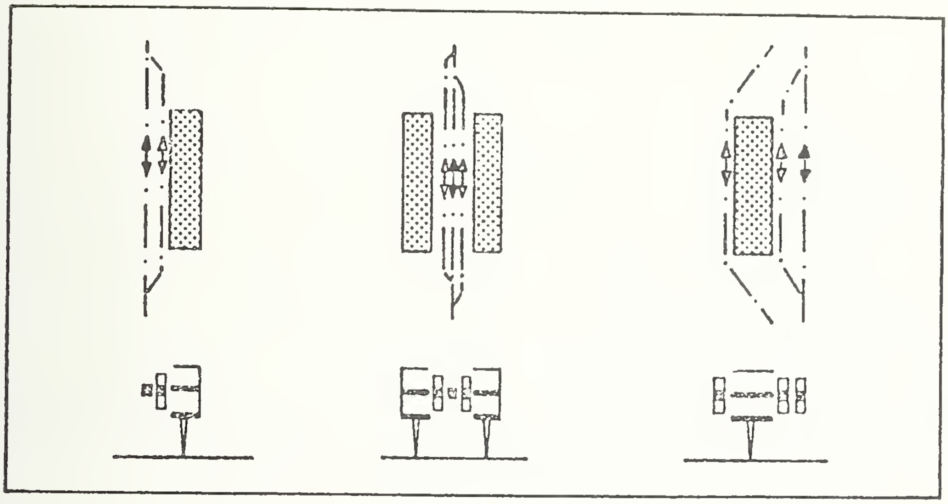


Figure 4-57. Basic Design Options for the Arrangement of the Cabintaxi Stations

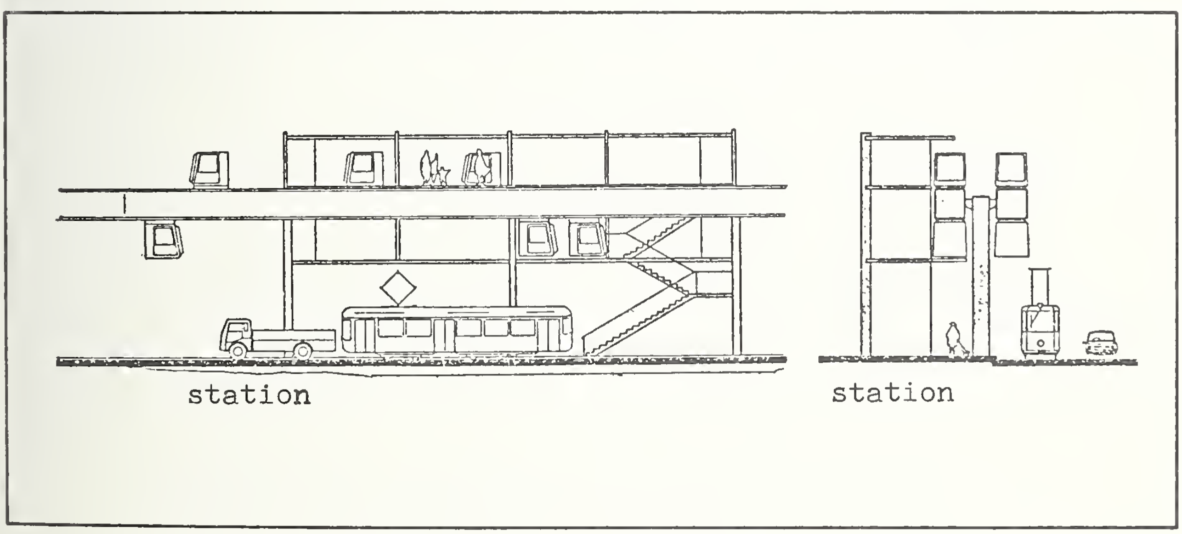
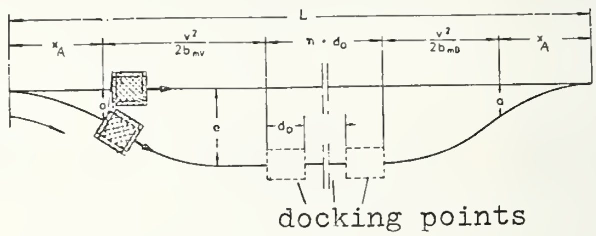


Figure 4-58. Off-Line Station



L = guideway length at the station

x_A = separation section

a = 1.94 m = distance between the guideway middle lines at the contact point

e = 2.94 m = distance between the guideway middle lines at the point of parallel arrangement of the main track and the station track

d_o = docking point length

n = number of docking points

$$L = 2\,x_A + \frac{v^2}{2\,b_{mV}} + n \cdot d_o + \frac{v^2}{2\,b_{mB}}$$

b_{mV} = deceleration (average)

b_{mB} = acceleration (average)

v = velocity

Figure 4-59. Determination of the Guideway Length and Between Guideway Dimensions for a Station

platform is determined by the number (n) of docking positions. For single cabin operation, a docking position length of 2.5 m is required for the KK3 cabin and 5.6 m for the KK12 cabin. The length of the off-line guideway is then calculated (see Figure 4-60).

$$L = 84 \text{ m} + n \cdot 5.6 \text{ m (KK12)}$$
$$L = 84 \text{ m} + n \cdot 2.5 \text{ m (KK3)}$$

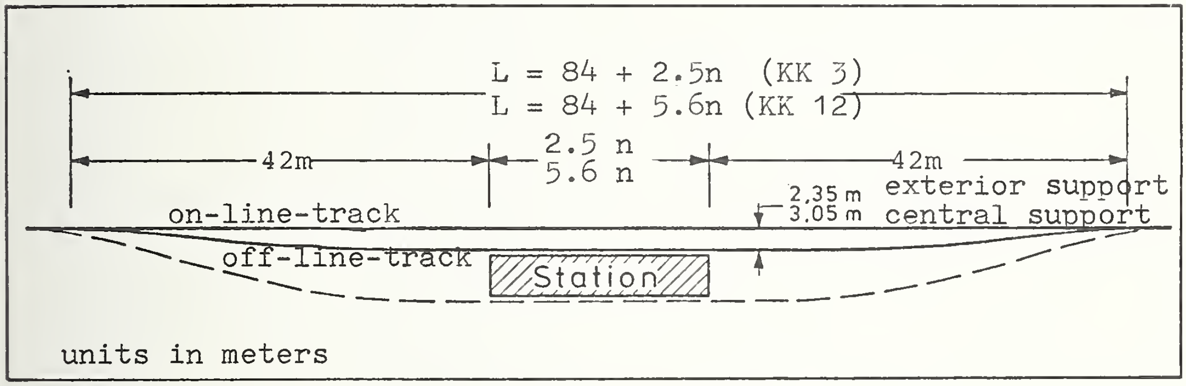


Figure 4-60. Calculation for Track Lengths of an Off-Line Station

BOARDING PLATFORM WIDTH

The width of the boarding platform is dependent upon the passenger traffic and the operational requirements of the system.

For line or scheduled route operation, the platform is designed similarly to those for on-line stations (see Section 4.6.2).

If discretionary operation is to be used, the cabin docking positions should have room for queuing passengers. For the three-seat cabin operating in this mode the platform width should be designed using the following dimensions (see Figure 4-61):

Safety range for boarding and deboarding	0.50 m
Waiting and access range	
for small stations	2.50 m
for large stations	

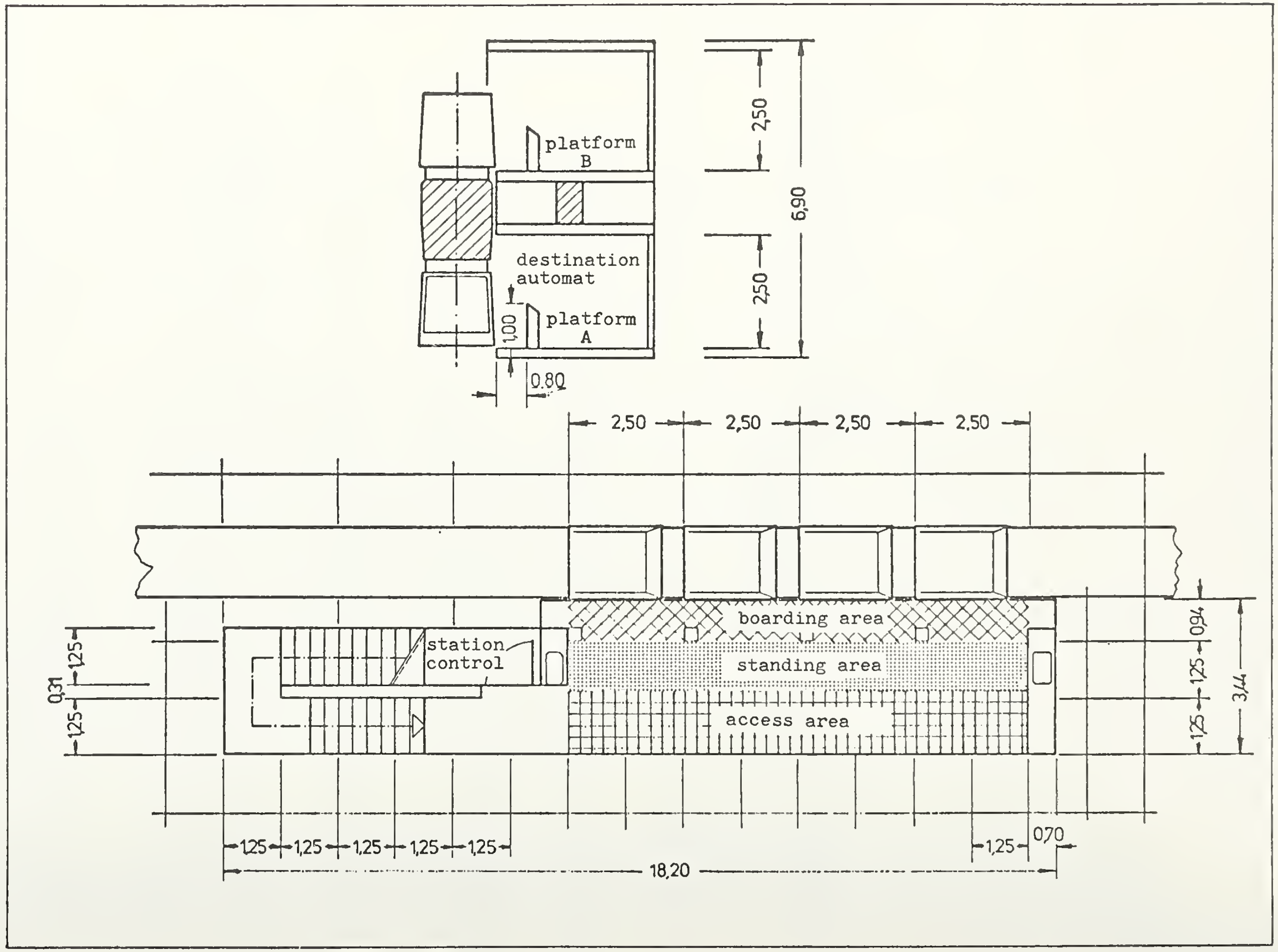


Figure 4-61. Schematic Diagram of a Station with Four Boarding Areas (Cabintaxi KK3)

(Access range 1.20 m)
(Waiting range 2.50 m) 3.70 m
(corresponding to a 5-person line)

4.6.2 On-Line Stations

On-line stations are arranged as conventional train stations on the through track sections. Approach and braking take place on the main track section.

Platform dimensions are dependent upon the operational concept and the way in which passengers are processed (see Figure 4-62).

For pure line or route traffic the manufacturer recommends the following dimensions (also see Figures 4-63 and 4-64):

Platform Length

The dimensions ofthe number of docking places for the single cabin is determined by the traffic load.

$$L- = n \cdot d_o \; ; \; d_o = \text{docking position length}$$

When cabins are coupled into trains, then the length of the longest train is determinate.

Platform Width

The width of the side entry platform is given by the manufacturer as 3.25 m + 0.50 m safety area. A center platform which handles a large amount of traffic should be 6 m which is the normal minimum width for a conventional rail station.

CABINLIFT STATIONS

Cabinlift stations are generally located in buildings. Figure 4-65 shows a planned Cabinlift station for the Central Hospital on St. Jürgenstrasse in Bremen.

For this special application, special attention must be given to level differences and protection from inclement weather between station and vehicle. The stations are sheltered by sliding doors to the outside. An entering vehicle

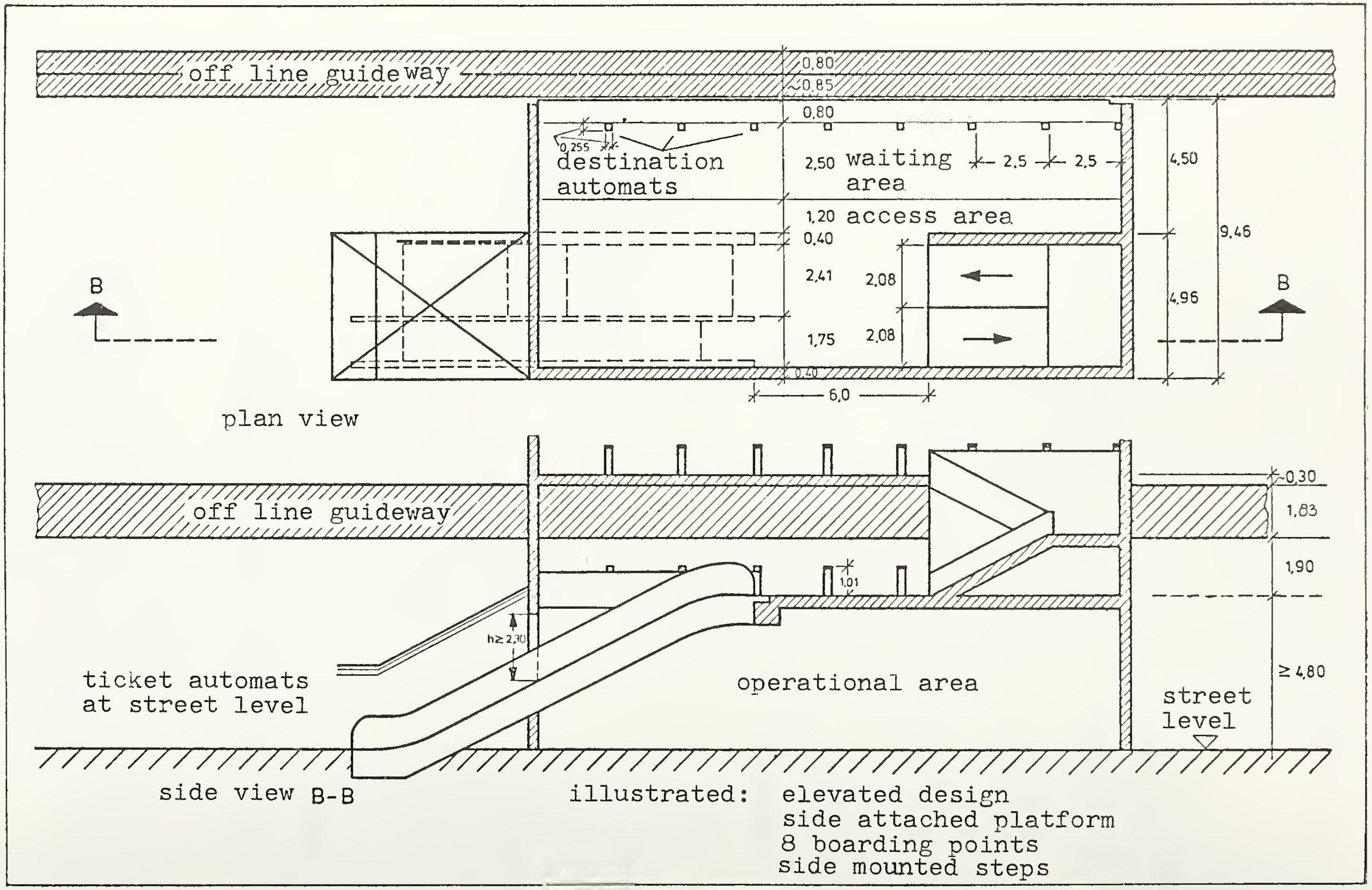


Figure 4-62. Schematic Diagram of a Station (Cabintaxi KK3)

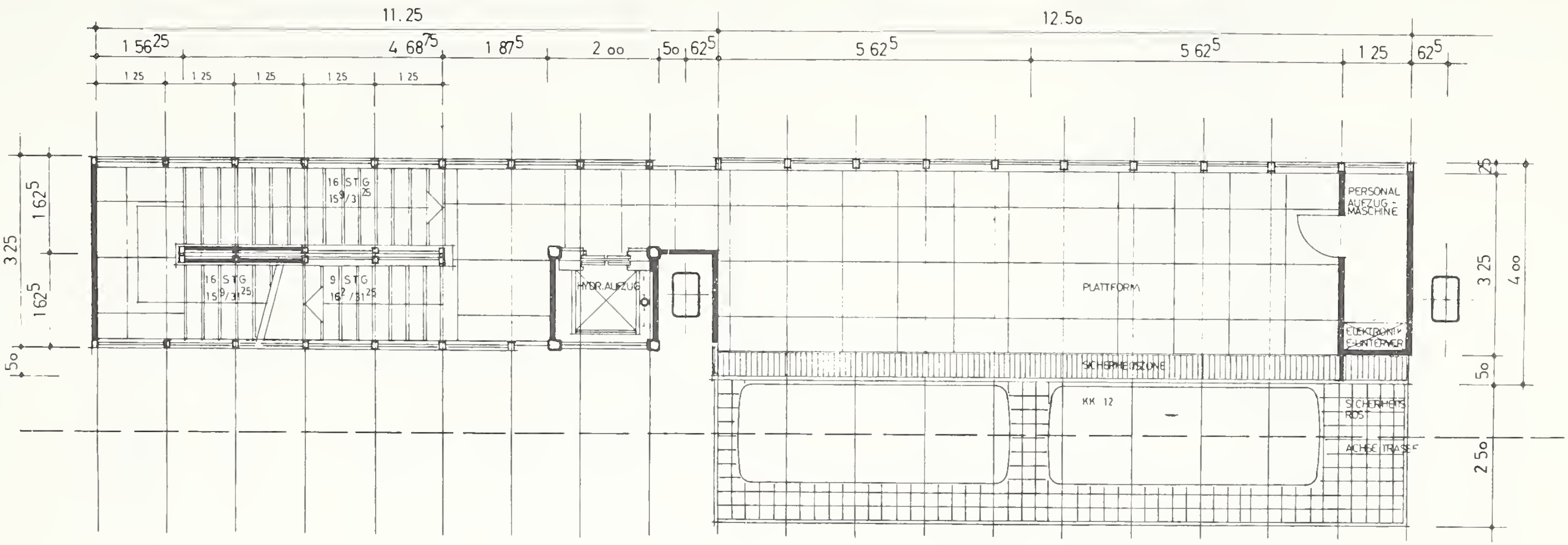


Figure 4-63. Schematic Diagram of a Station, Horizontal Projection (Cabintaxi KK12).

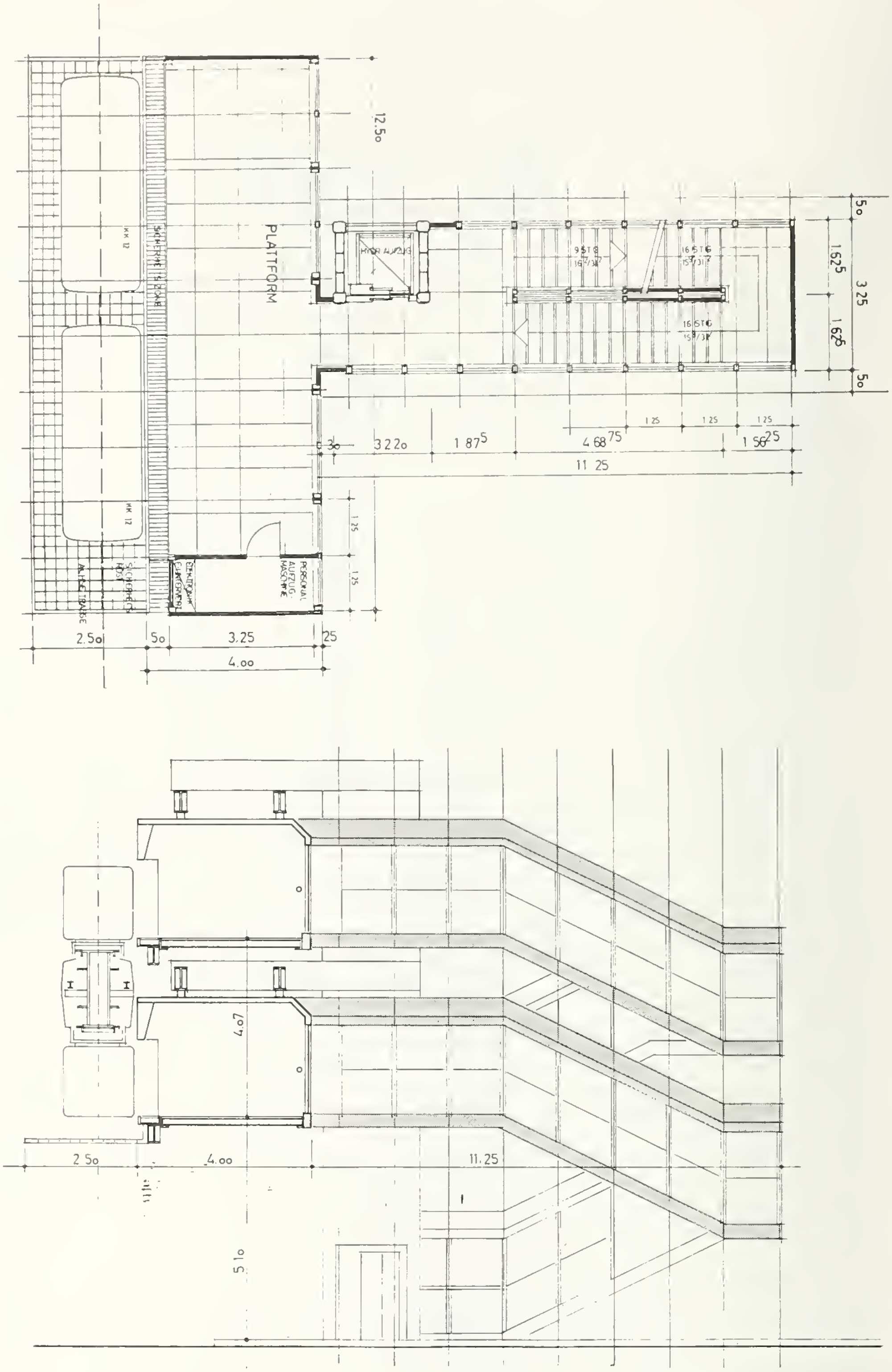


Figure 4-64. Schematic Diagram of a Station, Horizontal Projection and Cross Section (Cabintaxi KK12)

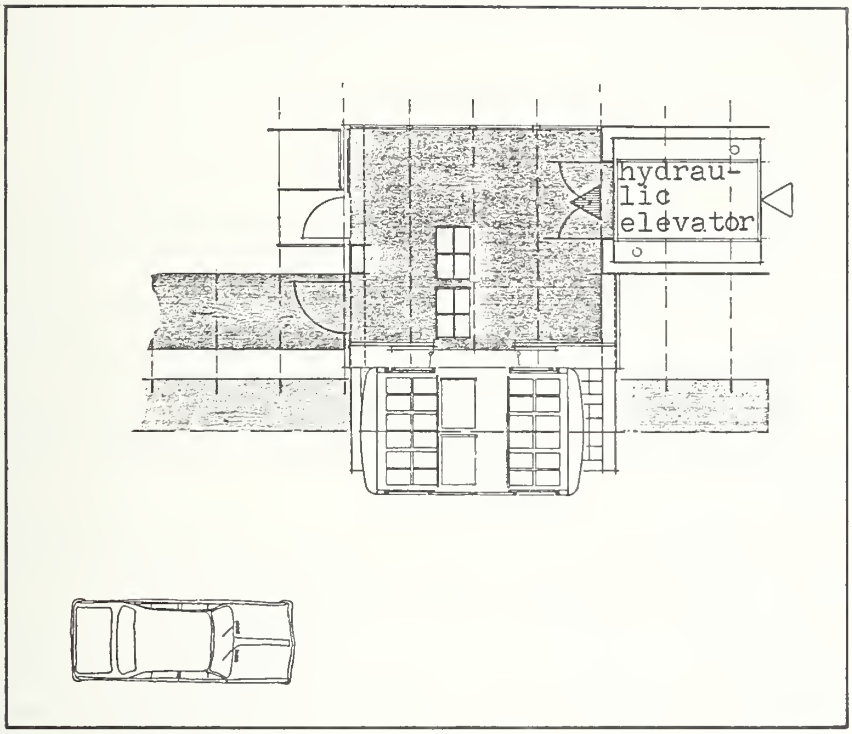


Figure 4-65. Example of a Cabinlift Station

is set to the proper level and docked before the station and cabin doors open in unison.

4.6.3 Two-Level Stations

The use of vertically stacked double guideways requires two different elevations for stations. The boarding platforms which serve guideways running in two directions, are vertically stacked. Ceiling height must be 2.50 m to accommodate pedestrian traffic. The lower platform has a higher ceiling because of the height of the guideway beam.

The height of the station building above grade is determined generally by the elevation of the guideway beams (see Figure 4-37, footnote 1).

4.6.4 Steps and Elevator Facilities

Stairs are arranged as shown in Figure 4-66. Large stations or those with an elevation from the entry level of 5 m or more, should have an up-going escalator, or in low traffic areas, an elevator. Back up areas should be provided at the foot and head of stairways.

The stairway width should be in multiples of 0.60 m (traffic band widths).

Landings and catch basins (or troughs) for janitorial service should also be considered.

For escalators, an installation width of 1.75 m with a useful width of 1.0 m would be practical.

The head room above the steps should be the normal minimum of 2.50 m. When necessary due to construction, the head room can be 2.30 m.

4.6.5 Station Equipment

Stations must be equipped with all necessary automatic operational elements appropriate to the operational strategy of the system. In addition to equipment for station control (see Section 4.2.4), other elements include those required for operation, information transfer, passenger handling, and equipment for passenger safety.

Reference [17] suggests the equipment listed in Figure 4-66 for passenger handling in the 3-seat Cabintaxi.

When other operational strategies are used, additional equipment may be required. Handrails are used to separate passengers in the station waiting area appropriate to their destination [4]. A revolving gate is used to limit the number of waiting passengers allowed in the area.

KEY TO FIGURE 4-66

(2) Transport system symbol at the entrance to the station

(3) Name of the station posted at the entrance

(4) Designation of line display

(5) Clock

(6) Diagrammed access to the loading platforms

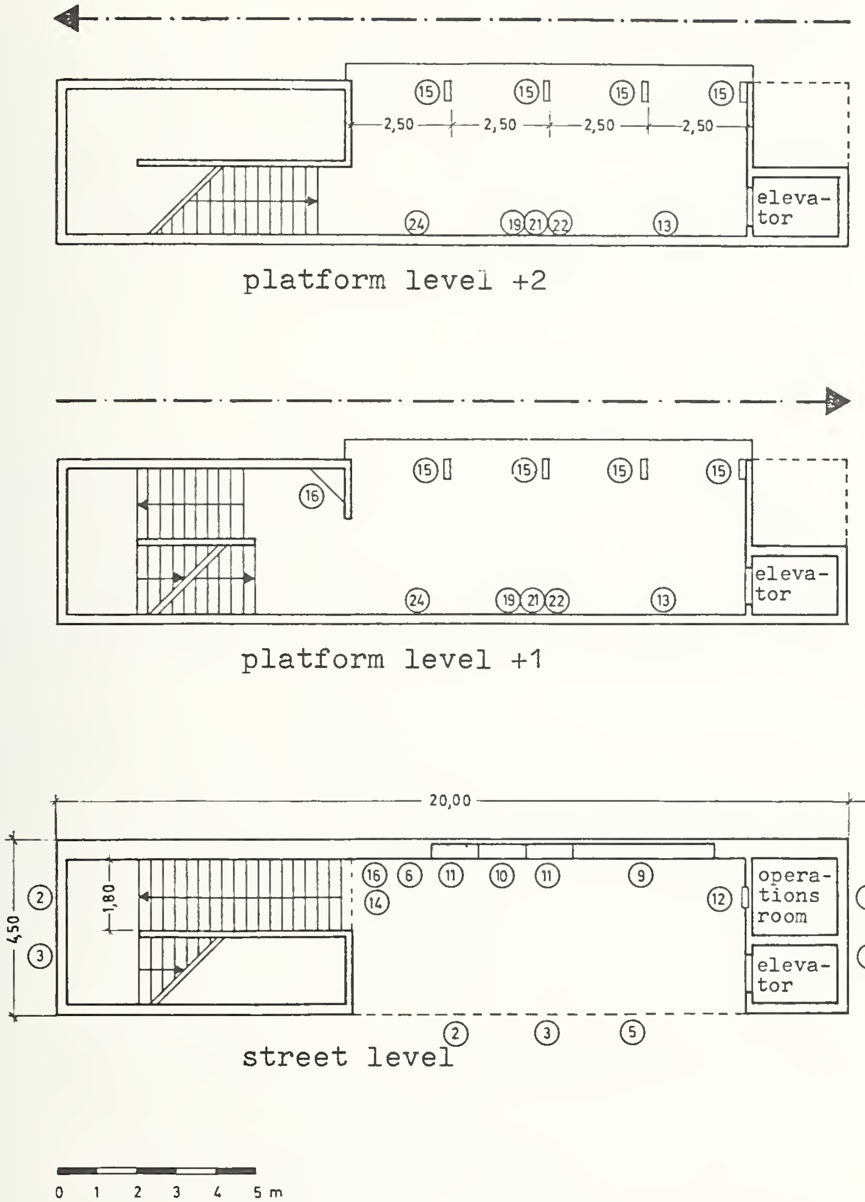


Figure 4-66. Model of a Station (Cabintaxi), Stacked Platform Levels

(9) Information showcase or display in the information and passenger handling areas

(10) Schedule of fares

(11) Travel ticket machines (ticket destination machines)

(12) Bulletin or information column

(13) Pictogram for the personnel elevators

(14) Entry markings (areas where a valid ticket is required for entry)

(15) Ticket cancellation equipment

(16) Marking of handrails indicating the boarding platform

(19) Station name displayed on platform

(21) Exit information displayed on platform

(22) Transfer information

(24) Street map of immediate area

Monitoring of the station area through fixed and rotatable TV cameras to insure passenger safety is recommended.[17] The station should be equipped with telephones for contacting operational personnel. In addition, fire extinguishers should be available and if possible, an emergency train stop handle.

TV monitoring can be handled from central control in a rotating fashion, or automatically switched on when one of the emergency call signals is activated. Sufficient night time station lighting is required (at least 750 Lux) to use the TV cameras. Fire extinguishers should be protected from vandalism, theft, and misuse. Central control should have the ability to release the fire extinguisher moorings in case of fire.

4.7 FARE COLLECTION (KK3-DISCRETIONARY SPECIFIC DESTINATION OPERATION)

The tariff and ticket system will be determined by the operational concept of the specific Cabinrail system (see Figure 4-67). It is determined by the question if it is necessary to code the destination into the travel ticket and load it into the vehicle. For the normal schedule-controlled line operation, however, ticket cancellation may be done as in conventional public transport systems.

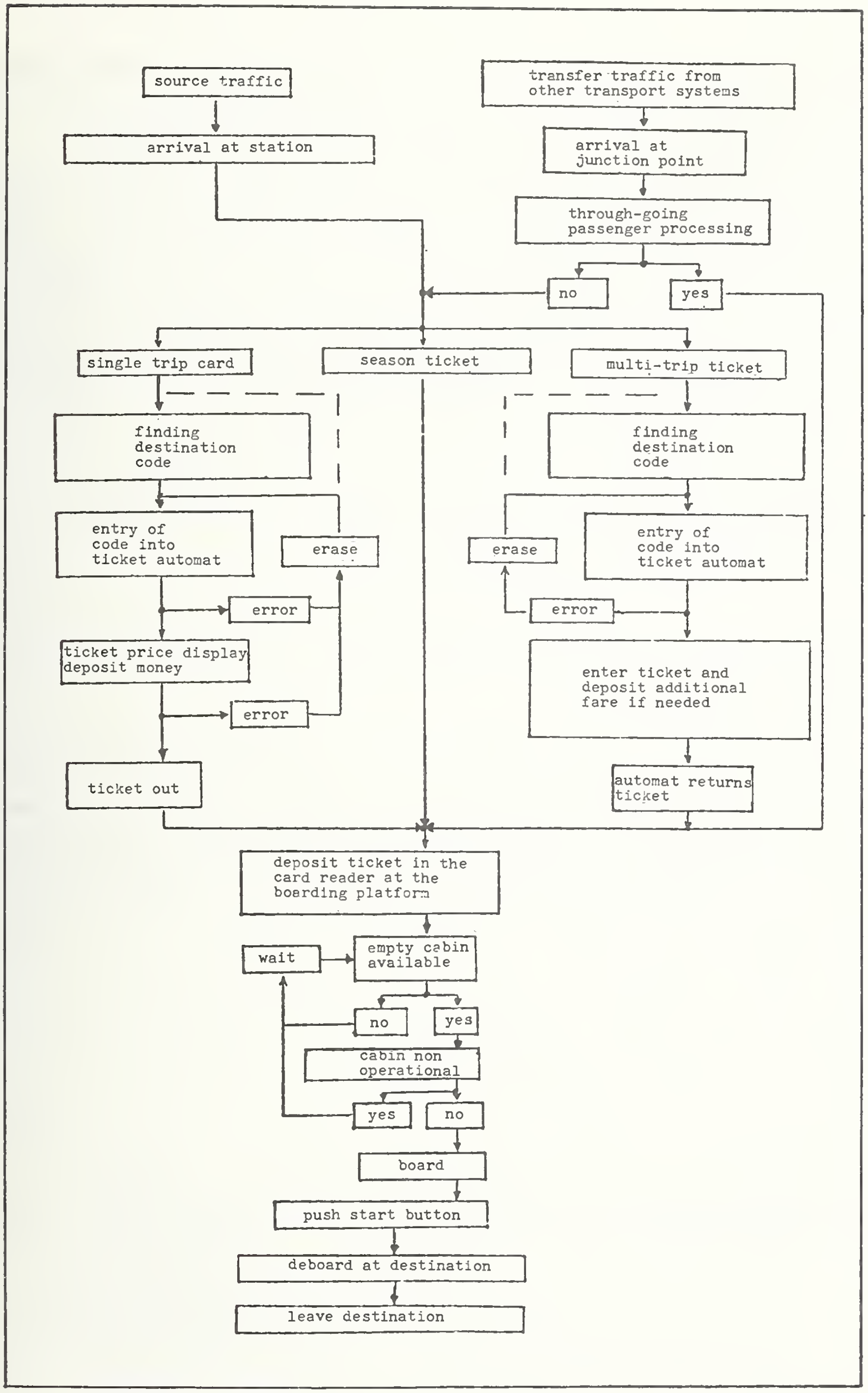


Figure 4-67. Passenger Processing Procedure

In the case of discretionary specific destination travel of the Cabintaxi, purchase of the ticket is usually coupled with the selection of the destination. The destination must be coded into the travel ticket either magnetically or with a hole-punch method. This should be accomplished on ticket purchasing machines (automats) in the passenger handling area outside the boarding area. These ticket areas should have a station map so that the station number of the destination can be directly read and entered into the automat via a pushbutton panel. Single tickets are supplied by the automat upon insertion of the proper amount of money in coins. When the destination station is coded in, information for the proper platform to be used should be displayed.

At every cabin docking point along the platform, a destination automat should be available. The travel ticket must be inserted into this machine to be cancelled, and to load the destination code into the vehicle.

Figure 4-67 illustrates schematically the described passenger handling procedure for the use of single-trip cards, as well as two types of season tickets (multi-trip tickets).

The dimensions and performance data of the ticket purchasing and coding automats, as well as the destination automats, are shown in Table 4-2. The determination of requirements of the number and types of ticket machines for a given station is dependent upon the size and composition of station users (for example, the number who pay cash, and the number who possess multi-trip cards) (see Figure 4-68).

Table 4-2

TICKET MACHINE DATA

Equipment	Dimensions	Capacity
Ticket sale and coding automat in passenger handling area	W/L/H (m) 0.43/0.43/1.135	Passengers paying cash = 20 passengers/h Passengers holding multi-season passes = 360 passengers/h
Destination automat on the boarding platform	W/L/H (m) 0.255/0.255/1.010	360 passengers/h

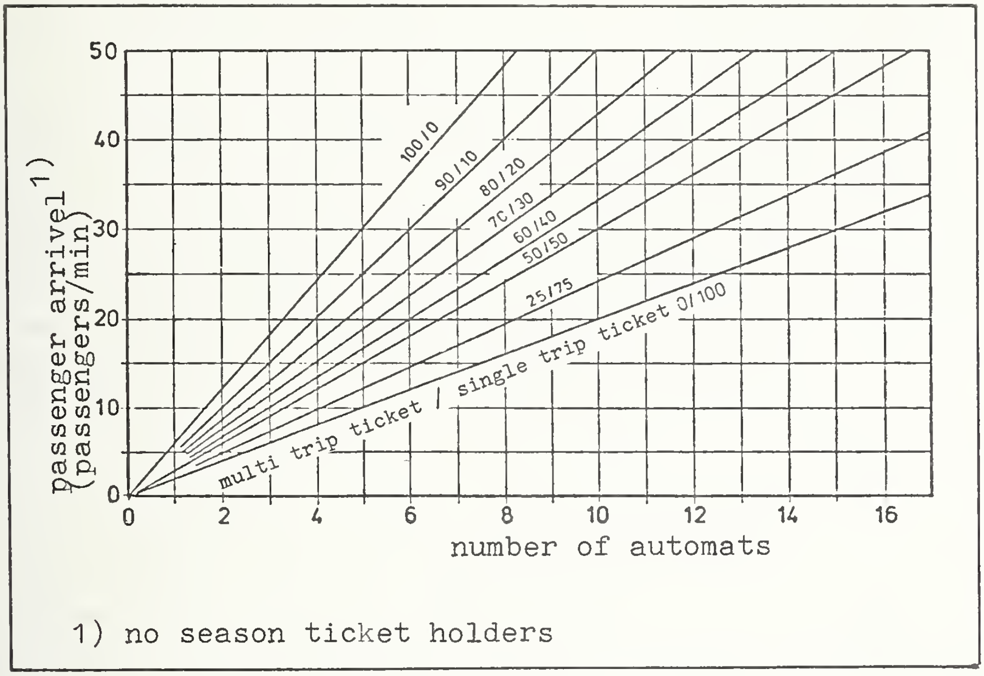


Figure 4-68. Number of Ticket Automats vs Passenger Arrival Rate

The procedure at the ticket automats is somewhat varied for the use of multi-trip or season tickets, which are valid only between specific stations whose identifications are permanently coded into the tickets.

Magnetic travel tickets which have a magnetic running account, such as those used for obtaining cash with credit cards, are also envisioned. The price of travel is subtracted from the balance at each use until the balance is zero (0). The validity period of the card can be increased by a further payment of cash.

The checking out of passengers at the destination station is unnecessary since it is impossible to travel further than the station coded into the ticket. The use of one valid pass by several persons, or the invalid transfer of tickets to unauthorized persons must be prevented by the use of spot checks. Therefore, it is required that special tickets or season tickets be coupled with a pass displaying a picture of the owner.

The passenger handling system discussed here requires the use of codeable travel tickets as mentioned at the onset, and the coupling of travel ticket purchase with destination selection. The Cabintaxi however, in general, might be integrated into a conventional public transport system or become part of a composite transport system. According to the circumstances and/or the extent of Cabintaxi operation, the existing ticket handling procedure must be modified to accommodate the Cabintaxi system. It is also possible that the Cabintaxi ticketing system could be used throughout the entire composite transport system. If the destination coded travel tickets are to be used for the Cabintaxi as part of a general transport system, then the capability for coding in the final destination with the Cabintaxi system must be provided at all stations in the public transport system.

The use of an existing ticket system to accommodate the Cabinrail system is possible by separating ticket purchasing and vehicle destination coding. The stations along the Cabinrail network would have the conventional travel ticket equipment and the necessary ticket checking could be made at the station exit. For operation of the Cabintaxi vehicle, an apparatus for entering the destination can be set up at the docking point; or in the case of simple systems, a method similar to that used in elevators, whereby destination coding is done through a pushbutton panel might be used. In this case, however, automatic control of ticket validity by the destination automats is missing.

4.8 OPERATIONAL SUPPORT

4.8.1 Energy Supply

MAIN POWER SYSTEM

The energy supply for the Cabintaxi and Cabinlift system is 50 Hz three phase with an operating voltage of either 500 V or 380 V. Higher voltages are possible (max. 660 V or 1000 V). As protection measures against excessive contact voltage, a protective conductor system has been selected.

The power rails consist of four side-mounted rails stacked one on top of the other. They will be discussed in detail later.

Operational energy for the network would generally be obtained from public voltage mains (10 KV), and fed to the guideway through a substation.

A study by the BBC in Mannheim, in 1976, investigated the energy supply characteristics which might typically be found in German public power mains capable of supplying 10 kV at a required voltage stability of +6%/-4%, and a short circuit power max. = 350 MVA/min. = 35 MVA.

> BBC: "It is apparent that the public mains must be considerably augmented for connection to the Cabintaxi system. It is pointed out that special cables must be laid to every Cabintaxi substation in order to achieve the required supply reliability.
>
> "The necessity that a mid-range (10 kV) voltage network be involved in the planning of the main power supply for a Cabintaxi system, does not mean that this mid-range voltage network can not be from the public mains. The mid-range voltage network must be planned especially for the requirements of the Cabintaxi system, so that its performance and reliability are adequate. The planning should determine the need for full or partial use of power grids or 2-ended feeding of power supply sections, in order to contribute to the economy and reliability of the system."

A compromise is required in the sizing of the feeder cross section, which takes into consideration operational requirements as well as cost factors. The determining factors are the traffic peak loads, including any exceptional operational situations (for example, the energy required when many vehicles are starting up after an operational malfunction). The compromise solution was to temper these exceptional operational conditions, e.g., by using sequential starts after an operational malfunction.

Further subjects addressed the BBC investigation were;

- Equivalent circuits for the design of propulsion systems.
- Equipment for compensation of reactive power effects and harmonic current oscillation.
- The effect of oscillations on the public mains and environment

In a comparison between an adjustable reactive compensation circuit mounted on the guideway (central to each feeder point or decentralized), and a fixed compensation on the vehicle, the latter was given clear preference. Advantages are small residual harmonic oscillation, low investment, and low maintenance costs. However, it does increase the weight of the vehicle by 120 kg.

Research concerning the extent harmonic waves effect the environment by induction into signal carrying inductors (for example, telephones) resulted in the conclusion, that for small harmonic waves (low in amplitude), no effect is to be expected.

The total effect by the system on a medium range voltage network of 10 kV is within the allowable limits when the tuning of the reactive circuit is carefully done.

POWER RAIL/POWER COLLECTOR SYSTEM

The power collectors are located on either side of the vehicle (Figure 4-69). When negotiating merging switches or branching switches, the power collectors are used on alternate sides. Each power collector is fitted with two redundant separate sliding contacts. Dense cabin traffic requires the largest possible conductor rail cross section. The carriers at the EPA have a cross section of 260 x 120 mm. Four parallel current rails are used (Figures 4-69 and 4-70).

With the exception of a few carrier sections, the power rails are located on only one side of the guideway. The minimal interval between the power rails and other grounded components is 35 mm.

The power rail cross section is about 1000 mm^2/phase, a symmetrical double-T, full profile rail. It is made from AlMgSi 0.5 (Figure 4-71), with a stainless steel running surface. On the basis of experience gained on the circle test stand at the EPA, future rails will be cooper coated aluminum.

The rails have higher mass and cross section concentrated at the contact area to achieve a high level of self-damping along the power rail. This concentration of mass results in a lower current displacement, and allows a higher efficiency of the power rail cross section.

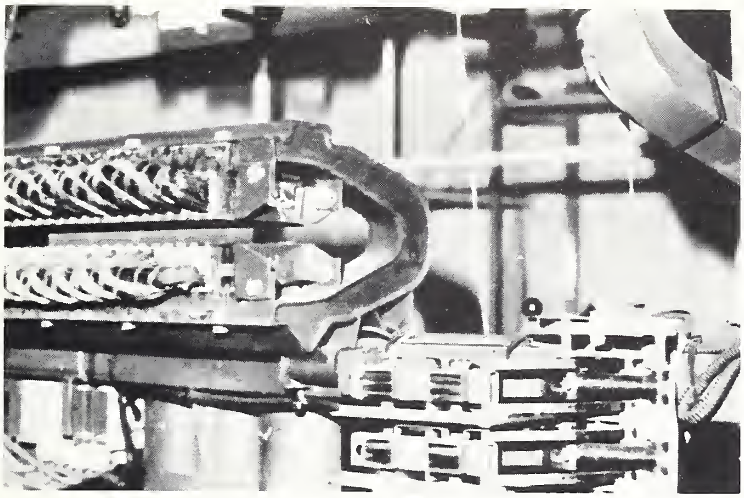


Figure 4-69. Power Collector Assembly

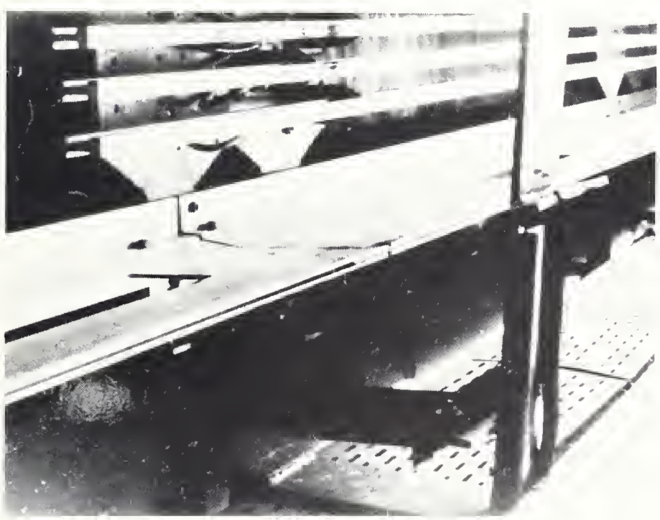


Figure 4-70. Power Rails Installed in Guideway

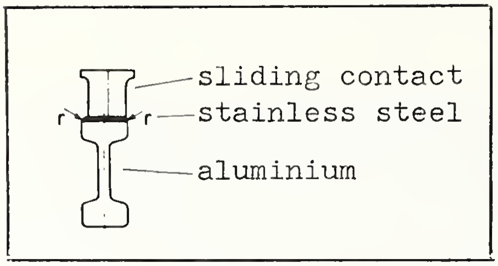


Figure 4-71. Power Rail and Power Collector

The power rail, including the protective conductors are attached at 2 to 2.5 m intervals and insulated with glass fiber reinforced polyamid. This support interval corresponds with that of the reaction rail for the linear motor (LIM). The normal length for power rails is 12.5 m.

The power rails are attached with expansion bindings at fixed points every 40 m.

The present power rail/power collector system has been the subject of a large number of test runs, however, the development is not yet completed.

A developmental objective of 1 year running time for the sliding contacts corresponding to 50,000 km will probably be far exceeded on the basis of tests at the EPA [14].

4.8.2 Depot Facilities

Vehicles which are not in operation during low usage periods on the system are called into depots to avoid unnecessary travel of empty vehicles, and in addition, to protect vehicles from the influences of weather. From these depots the vehicles can be called out as necessary.

LOCATION AND STRUCTURAL DESIGN

During peak traffic times the network connections must be such that one or more stations can be supplied with a sufficient number of vehicles.

If the passenger use of one station is significantly higher than that of the other stations, the connection of the storage depot to a line can be made by means of a guideway ring (Figure 4-72). Top-mounted and suspended guideway

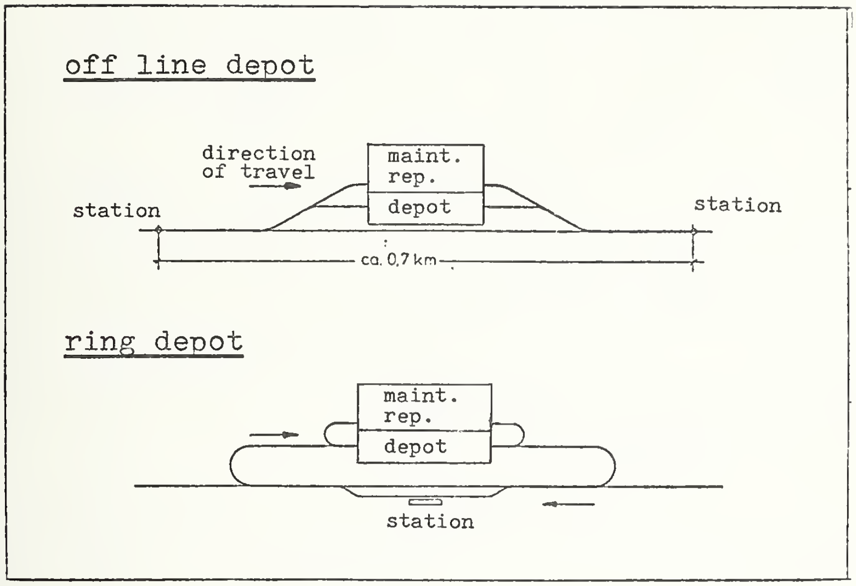


Figure 4-72. Depot and Maintenance and Repair Facility

could lead directly to the appropriate station, that is, in-coming vehicles at both guideway levels could be immediately stored and called back directly to the same station when needed.

Dispatching from main depots requires that a connection be made with an off-line track section (Figure 4-72). A guideway ring (loop) would not normally be used for this purpose. The stations on either side of the depot would have only one guideway level directly connected to the depot.

In a traffic network, depots would be integrated with maintenance facilities.

A basic design for the location of off-line depots, as well as an example of track design and layout, is given in Figure 4-73 and 4-74 [18].

The depot consists of an approach section, partly covered storage sections, and a departure section. Entry and departure to the depot would be

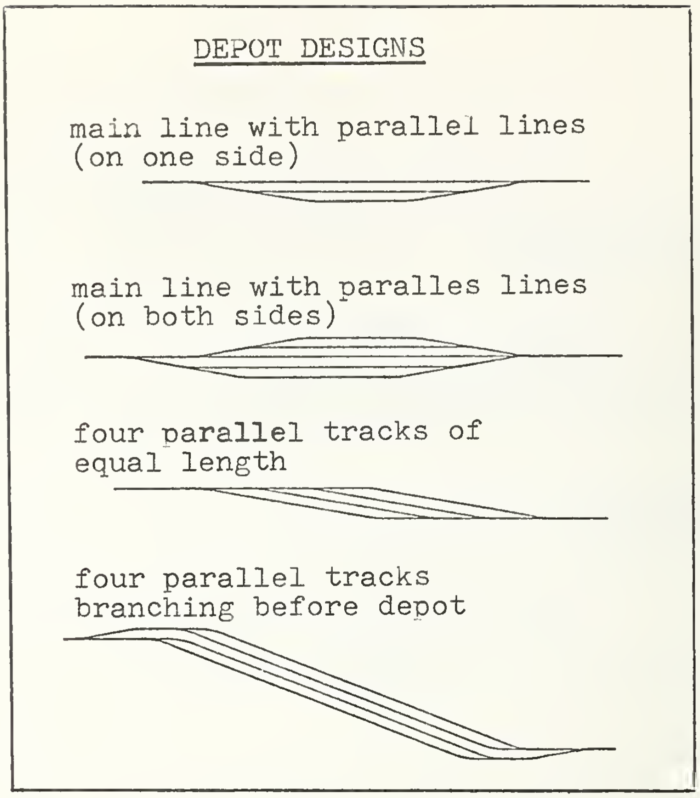


Figure 4-73. Depot Designs

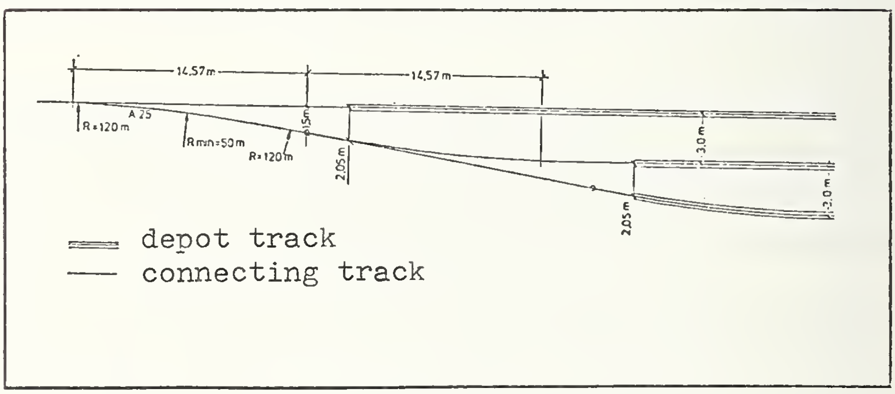


Figure 4-74. Layout of a Depot Connection

accomplished by either active or passive switching, or by some type of towing or other mechanical conveyance equipment.

Inspection of the guideway in both the suspended and top mounted vehicle systems is accomplished by a walk-way mounted at the side and between the guideway beams. Steps are located at either end of the depot for entrance to the walk-way.

LOCATION IN THE NETWORK

The location of the depots is either in the form of large central depots (main depots), or in the form of smaller depots spread throughout the network. The building of main depots allows the vehicles of a given network to be collected into one building. However, it must be realized that the large concentration of vehicles requires a much greater area for the building.

From transport and economical viewpoints, the location of just one of several depots throughout the network would be determined based on the desire to minimize the number of kilometers traveled by empty vehicles. The location of these depots may be determined by calculations and/or dynamic simulation (see Section 4.13).

The 3-seat cabins used in specific destination and discretionary transport require decentralized distribution of the depots. Special depot side tracks, as well as station side tracks, would be used for proper distribution of the cabins. There is also a "dynamic" storage aspect to the empty cabins which are circulating on the network.

For scheduled line operation, storage depots equivalent to present conventional rail systems are possible. That is, central depots with connected repair facilities and storage tracks with connections to individual stations could be provided allowing vehicles to be fed onto and collected off of the network.

4.8.3 Maintenance Facilities

Regular inspection, repair, and cleaning of the vehicles is carried out in the maintenance facility. Due to the large number of individual automated vehicles, there is a requirement for automatic functional check-out and repair of the vehicle systems. Check-out stands are limited to the electronic components. The functional parameters (input and output signals) of the various

components will be measured, and then compared to acceptable values which will be given in a check-out manual. In case the measured values deviate from the prescribed normal values the source of the error can be localized. A defective electronic component would be replaced in the repair facility.

The technical equipment for check-out and electronic maintenance has a capacity of 700 vehicles. If, because of the number of vehicles, only one repair unit is required, then a second unit should be planned as a reserve. (See footnote T.N., a "unit" in this respect is meant as a facility for servicing a given number of vehicles.)

In a transport network at least one depot would have a central maintenance facility. The maintenance facility should be located on a guideway parallel to the storage section, so that after maintenance, the vehicles can be directly fed back to the main line (Figure 4-72).

Cleaning the smooth cabin exterior is accomplished in a fully automated washing facility. The manufacturers recommendations suggest one exterior washing/week and daily interior cleaning.

4.8.4 On-Line System Repair Facility

For the simplification and efficiency of the maintenance process, the repair equipment is always integrated into a maintenance facility. This combined facility eliminates the need for vehicles to travel empty from the maintenance facility where a malfunction is detected, to the repair facility, where the malfunction is to be repaired.

Since the guideway has two levels (top-mounted and suspended), repair areas for the two types of vehicles must be different. The guideway carrier in the shop area must be designed to allow ease of access to vehicle components. The use of block and tackle for heavy components and scaffolding should also be planned for. Four special maintenance working levels for the top-mounted and

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T.N.: For the purposes of this system the terms "maintenance facility" (4.8.3) and "on-line repair facility" (4.8.4) are used to designate respectively the maintenance area in which electronic checking and inspection of the vehicles is made, and from which they are returned to service if no repairs are necessary (4.8.3), and the area of the maintenace facility in which necessary or indicated repairs are carried out (4.8.4).

suspended vehicles is also being considered. The use of moveable scaffolding would simplify the construction of the maintenance area. Maintenance Facility design concepts are currently being formulated.

The modular building-block system of cabin construction allows quick replacement of damaged cabin sections. Additional parts because of their modular construction are also easily interchangeable. The linear motor is side-mounted. Since this is a relatively light component, heavy or special equipment for its replacement or removal would normally not be needed.

4.8.5 Vehicle Rescue and Assistance Equipment

Special vehicles are planned for routine maintenance and support, and in addition, to handle operational failures and recovery of passengers from disabled vehicles. These special vehicles would be equipped with an auxiliary drive separate from the normal power and propulsion system.

A multi-purpose vehicle designed to both recover stranded passengers and to carry out small repairs on both guideway levels is required. Such a vehicle would be stationed at various points along the network and be able to reach defective cabins from either direction of travel. This multi-purpose vehicle would be able to push or tow defective cabins after having approached them on the same track level. To carry out heavy repair, the stranded vehicle would first be made mobile, and then directed or pushed/towed to the maintenance facility.

A service and recovery vehicle similar to this is presently in use at the test facility in Hagen. It is fitted with a side-mounted platform which can be extended in the front and rear directions, as well as swung out over the track (Figure 4-75). The vehicle is manually controlled, auxiliary drive is not yet available.

Using this vehicle, passengers can be recovered from the rear section of the KK12 cabins. The vehicle has hydraulic telescoping feet which fit against the guideway beam for stability. This vehicle has been equipped with the mechanical parts necessary for vehicle coupling. The electrical connection for signal transfer is presently in development.

Figure 4-75. Service Vehicle

If a single guideway is used, the service vehicle can be designed to run along the top side of the guideway beam. This service vehicle can pass approaching vehicles sideways (Figure 4-76). The vehicle is driven from controls in the open basket.

Figure 4-76. Service Vehicle on Single Track Guideway

Use of this vehicle in a meshed network requires that a drive mechanism be developed, which can negotiate switches and switching points.

4.9 SAFETY FEATURES

The safety features developed for the Cabintaxi will be discussed in this section. Section 5 of this study provides more detail as to their present state of development.

This section addresses all three variations of the Cabinrail system, (i.e., 3-seat small cabin, the 12-seat cabin, and the Cabinlift). This is possible because all components such as vehicles, switches, etc., are variations of the same concept. The same automation components are used in all variations.

The subsystems for the 3-seat and 12-seat cabins, as well as the Cabinlift, are the same. The Cabinrail systems differ only in the quantitative way in which these subcomponents are assembled. The same modularity philosophy exists in the design of small and large cabin networks.

4.9.1 Defintions

The concepts of "safety" as used here indicates the probability that within a given time interval (for example, within 1 hour), or during a predetermined operation (for example, during a given transportation event, i.e., passenger kilometer or vehicle kilometer), no accident will occur within the system or within the transport process defined.

"Accidents" are defined as any injury or damage caused to personnel or material by the system (other than trivial damage). Examples of accidents not included are falls from the platform, or in the approach area, stairs, or escalators, which at the present time account for the large majority of accidents on subway systems. The system concept and technical design will have little effect on these accidents, however, such items as slip-proof flooring might be incorporated in order to reduce the problem. The concept of "safety" is still further limited. As defined here, safety does not include the security of passengers from criminal acts. It should be noted, however, that the small cabin system because of its mode of operation (destination specific with each passenger or group of passengers in their own vehicle) offers good protection from assaults. In addition, the normal precautions which might help to discourage criminals, such as video monitoring of stations, are also utilized.

The discussion of safety in this section of the report is not concerned with the protection of passengers from criminal acts, but only with their protection from the results of a technical defect.

The principle of redundancy is defined as the availability of more than one functional channel for the accomplishment of the same task. The parallel use of several functional channels can increase the safety and reliability of a system.

4.9.2 Types of Malfunctions

The various technical problems considered possible over the entire system are categorized as A, B, C, and D according to the severity of the effect they cause.

A) Malfunctions which may cause an accident
In this category are all malfunctions which may result in an accident, even in the case when an accident does not necessarily result.

B) Serious operation malfunctions
This category contains malfunctions which can cause a blockade of sections of the guideway or the station.

C) Slight operational malfunctions
This category would include cases in which speed in the vehicles may be somewhat decreased, or the interval between vehicles may become lengthened.

D) Not critical
These are malfunctions which have no direct effect on the operation or on safety, and may be corrected at the next scheduled maintenance.

Only malfunctions in category A, which lead to the possibility of an accident, are important in the consideration of safety. The B to D categories are important in the area of reliability (Section 4.10).

Single malfunctions are differentiated from multiple malfunctions. Multiple malfunctions are defined as, several statistically independent malfunctions occuring within a given time interval.

4.9.3 System Safety Philosophy

The basic system safety philosophy for the Cabinrail system can be formulated in two sentences:

1. A dangerous situation must never result from a single malfunction.
2. Multiple malfunctions, the result of which can create a dangerous situation, must be extremely inprobable.

The effect of any imaginable single malfunction must leave the system in a safe condition (fail-safe principle). This means that either the system can continue to operate in a safe manner, or when this is impossible, that the system or the defective subsystem immediately reverts to a safe mode or condition. The stopping of a given vehicle or all vehicles along a given section of track is considered to be a safe condition.

According to recommendations of the British Air Registration Board (British Civil Airworthiness Requirements), and American requirements according to Federal Aviation Requirement - 25, (valid for German certification in civil aviation), any failure which leads to a situation that can endanger safety must be of the "highest inprobability." A more exact probability value is not directly given, however, from definitions of other danger scales it is assumed that highest improbability corresponds to an occurrence of

$$\leqslant 10^{-10} \text{ per operational hour.}$$

A double failure can only be classed of the highest improbability when both failures belong to the "improbable" category (those which have a probability from 10^{-5} to $10^{-7} \times h^{-1}$). In this case, the maximum total probability would be $<10^{-10} \times h^{-1}$. Another example is if at least one of the failures belongs to the highly improbable category (probability of failure $\leqslant 10^{-7} \times h^{-1}$). In this case, if the probability for the second failure is between 10^{-3} and $10^{-5} \times h^{-1}$, the required value of $10^{-10} \times h^{-1}$ for the total failures is met.

4.9.4 Safety Critical Components in the Cabinrail System

The most critical safety item is the headway control system, which is responsible for holding a speed dependent interval between a given vehicle and the vehicle preceding it. The selection of a technical approach to this function is important since the safe interval between two vehicles requires an active sensing of the preceding vehicle, and the transfer of an active signal between the preceding and the following vehicle. Since the absence of this interval measuring signal means free track, and therefore maximum operational speed, the safety measures described in Section 4.9.5 have particular importance.

An additional safety critical function is the control of the merging switches. Within the switch area, an interval measuring signal is transferred from one arm of the switch to the other (see Section 4.2.3). Failure of this signal transfer could cause the collision of two vehicles entering the V-point at the same time. Simulation calculations [19] have shown that a collision could only occur when the failure is in a range nearer than 6 m to the V-point of the switch. At this range, the conflicting vehicles would be traveling slower than 2 m/s. This situation is unlikely because of vehicle platoon dynamics, and additionally, the results of such an accident are limited due to the low speeds involved. This fact, however, does not reduce the safety requirement on the merging switch control.

Data transfer is the final critical safety subsystem over which the vehicles obtain information from the guideway system. The critical information transmitted by this subsystem is the allowable top speed for given track sections, and the commands for switching "on" and "off" the interval measuring transmitter. The transfer of top-speed data is a smaller problem since all track sections can be traveled at the maximum operational speed. A malfunction that allows for speed over the entire guideway will have an effect on passenger comfort because of the higher speed involved, but little effect on safety.

Switching off of an interval measuring transmitter constitutes a reduction in safety. It is normally capable of being commanded off only in switch areas and stations. At these times the headway control system becomes a single non-redundant element. To help minimize this problem, the data transfer subsystem has been designed to keep both transmitters on unless actively commanded to turn one off.

Station control, direction control to the demerging switches, and the network computer have no safety responsibility. Failure of these subsystems could lead to a disruption of normal operation, but would cause no accidents (see Section 4.10.2).

4.9.5 Options for Achieving System Safety

As discussed in Section 4.9.4, some system components do not completely meet the safety requirements outlined in Section 4.9.3 from their functional concept alone. The meeting of these requirements must be achieved through special additional measures. In principle, several options are available for the Cabinrail system. These will be presented in some detail before describing the particular safety concepts utilized.

The simplest and classical method for achieving safety is to design technical components which are already fail-safe in their functional concept. This principle, however, cannot successfully be applied to many components of the Cabinrail system. It has two disadvantages:

First, each malfunction could lead to a stoppage on the system; the "availability" would therefore be reduced.

Second, such designs may not be technically or economically practicable, for example, when applied to the headway control system.

A second method considered is that of disparity monitoring. Using this method, the individual functional units are equipped with a parallel monitor which continually checks for proper function. The monitor itself must operate according to the fail-safe principle, that is, it must be designed and constructed so that it outputs an active O.K. message during proper operation of the monitored unit. Failure mode analysis could assure that the O.K. message would not be transmitted in case of failure in the functional unit or the monitoring system. Figure 4-77 illustrates a block diagram of this arrangement.

The monitor can also consist of a simple comparator wired to two parallel functional channels. The comparator then checks to see that the output signals of each remain the same. The comparator itself must operate according to the

fail-safe principle. This variation on the monitoring principle is illustrated in Figure 4-78.

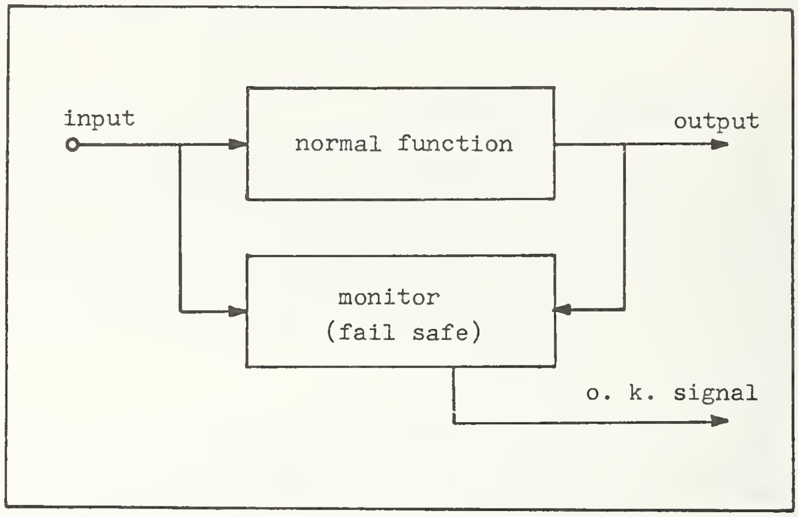


Figure 4-77. Block Diagram for Monitoring

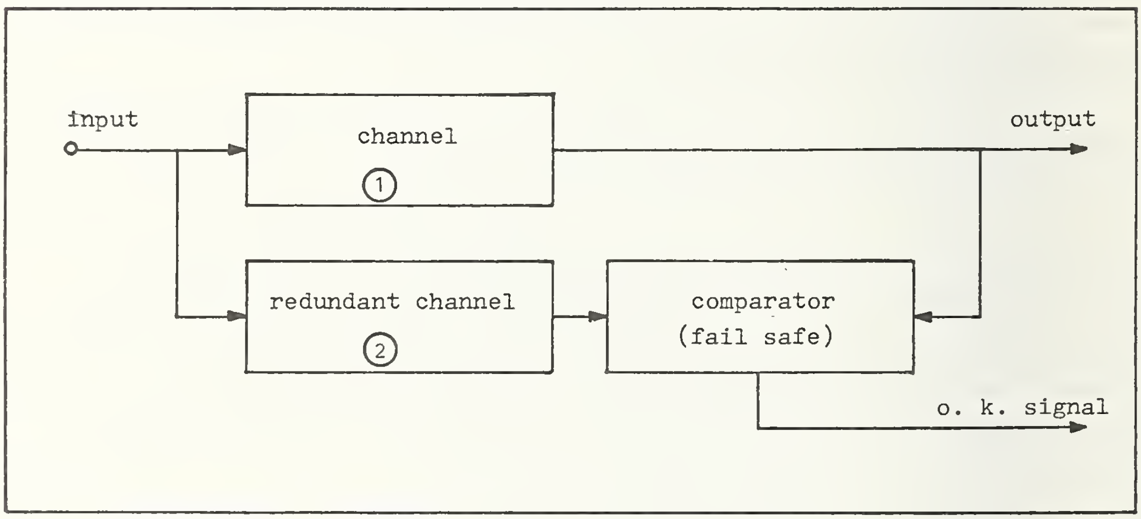


Figure 4-78. Block Diagram for Monitoring Function of Redundant Channels

The principle illustrated in Figures 4-77 and 4-78 for a fail-safe monitor assumes that the input values are correct or have been checked by another method.

The simpler version, (Figure 4-77), has the same disadvantage as a fail-safe design, namely, that every malfunction on the vehicle or on a given track section could cause stops and result in low vehicle availability.

The principal advantages of using two functional channels for monitoring, is that similar proven designs can be used in each channel, allowing the comparator design to remain relatively simple.

In the version shown in Figure 4-78 there is an option available to forward the safer of the two (for example, the smaller of the two), keeping the system in operation. This option could increase vehicle availability.

One of these forms of the monitoring principal would be used in systems where only a small probability of failure of the monitored system exists, for example, the interval measuring cable.

In order to increase vehicle availability, it is not only necessary to detect a failure but it should also be possible to correct the malfunction. Therefore, an additional safety method is being considered for the Cabinrail system.

This method would utilize three functional channels (see Figure 4-79). The channels would be divided into three pairs, each pair having its output signal going to one of three comparators. If the output signals reaching the comparators match, then that comparator transmits an O.K. signal. When the three output signals match properly they are merged into a common output signal. Each functional channel would be switched back to the common output signal only if both comparators to which it is wired give an active O.K. signal.

This arrangement would allow malfunctions to be detected in the functional channels, as well as in the comparators. A malfunction in one functional channel or in one comparator still allows the system to continue operating with two properly functioning branches. Additionally, the loss of the O.K. signal indicates the channel or comparator where the malfunction has occurred, allowing rapid trouble-shooting.

This triple redundant voting circuit would be used on the vehicles for the central portion of the control electronics.

4.9.6 Vehicle Concept

The interaction between monitoring units and the triple redundant voting circuit is presented in this section as an example of a possible vehicle control

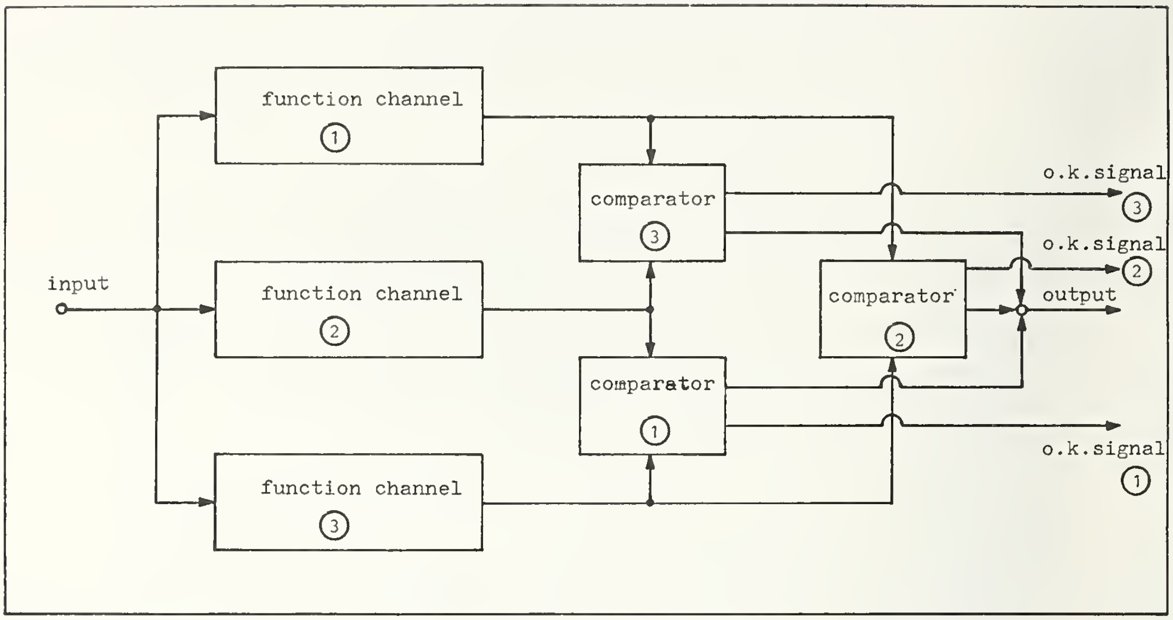


Figure 4-79. Triple Redundant Voting Circuit with Fail-Safe Comparators

concept. Both monitoring and voting circuits could be utilized in the implementation. The monitors can recognize malfunctions, and in cases where these may be critical, can bring the vehicle to a halt. The voting selectors can detect malfunctions and correct them. That is, in the case of a detectable malfunction the vehicle could direct itself to a maintenance facility, or under certain circumstances continue to complete its assignment before reporting for maintenance.

Figure 4-80 illustrates the block diagram of a proposed triple redundant vehicle control system. The vehicle control system controls the switching wheels, doors, mechanical brakes, linear motors, linear brakes, interval measuring transmitter, and other relatively unimportant (to safety) and therefore unillustrated items such as heating and light. The functions are divided into 10 different blocks, two sets of blocks forming pairs (transmitter right, transmitter left, and receiver right, receiver left). One of the 10 blocks, the power supply, is not shown in Figure 4-80. In case of power failure the vehicle control system remains functional, deriving power from an on-board battery.

The necessary inputs for operation of the system are power, the interval measuring signal derived from the two interval measuring cables, digital

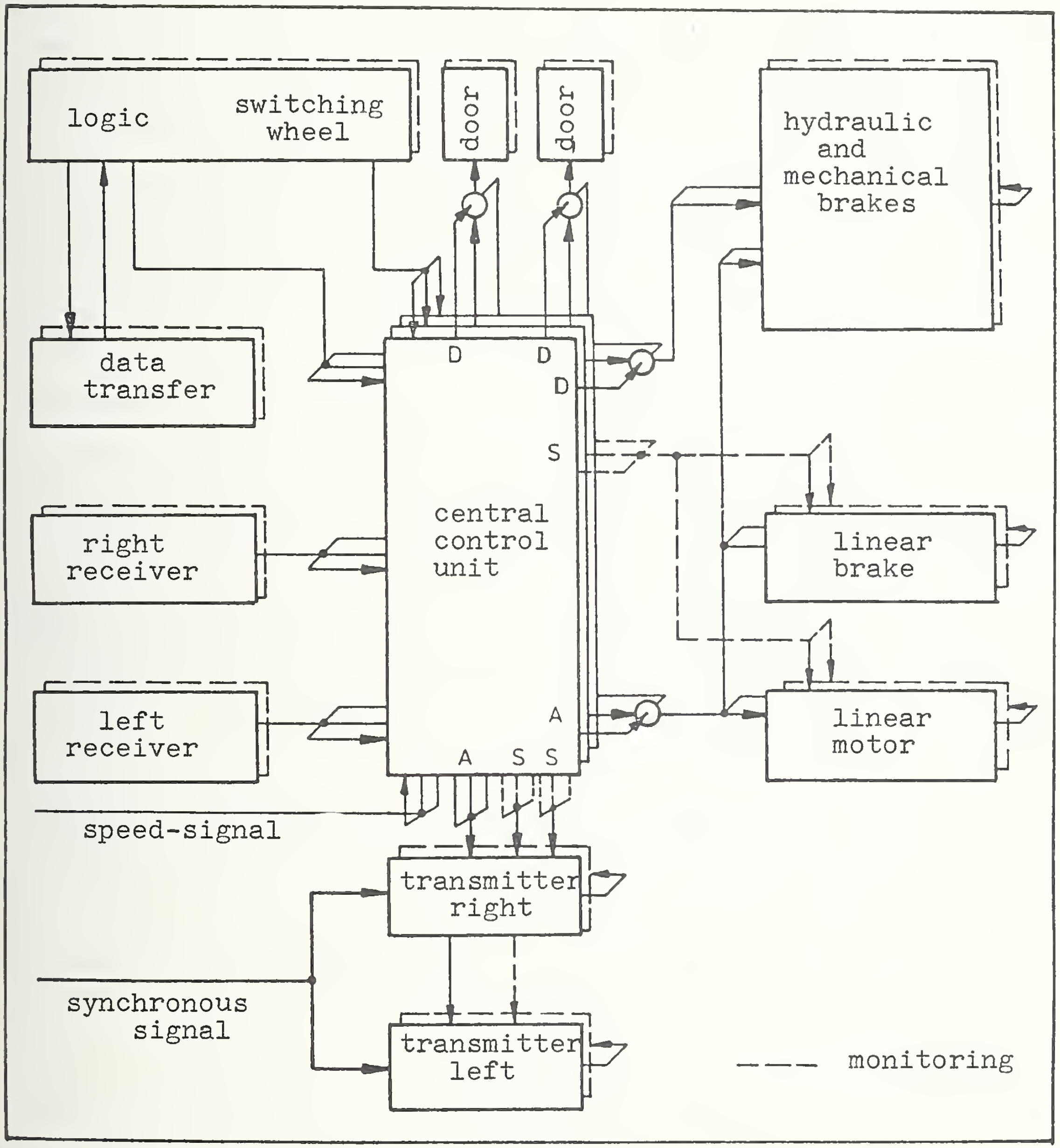


Figure 4-80. Redundancy and Monitoring Concept for the Vehicle

information which reaches the vehicle via the data transfer lines, and speed. In Figure 4-80 speed refers to the physical parameter which is first converted into a signal by the tachometer. The block drawn as the center control unit is not further divided. It contains almost all of the low voltage electronics and supplies two analog (A), three digital (D), and three switching signals (S) at its outputs. The central control unit would be triply redundant. The three output signals would be in an arrangement as shown in Figure 4-79. Because of this arrangement the output signal could be considered to be highly secure. The propagation of these output signals, for example, by transmitters or in drive and braking systems, is monitored by additional fail-safe monitor units. In this scheme the three channels which would supply input information to the central control unit, and which monitor the power supply, would be designed similar to those in Figure 4-77 and Figure 4-78.

O.K. signals transmitted from all of the comparators associated with this system would be evaluated by a malfunction logic section (not shown in Figure 4-80). The malfunction logic must function according to the fail-safe principle and respond to the loss of one or more O.K. signals by initiating appropriate vehicle reaction (see Section 4.9.7).

The concept illustrated in Figure 4-80 has not yet been implemented at the test facility in Hagen. The control system presently in use is single channel, and made safe by simple measures acceptable in a test environment.

The probability for a double failure with this triple redundant/monitoring safety design is extremely small. Reliability analysis on the central control unit showed a failure probability of $\lambda_A = 25.8 \times 10^{-6}\ h^{-1}$ for failure category A type accidents [21]. With a failure recognition lag time of the comparators of $\tau \approx 0.1\ s \approx 3 \times 10^{-5}$ h, the probability for a safety-critical double failure is reduced to $\lambda_{double} = 2\ \lambda_A^2\ \tau \approx 4 \times 10^{-14}\ h^{-1}$. The maximum acceptable probability of $10^{10}\ h^{-1}$ (Section 4.9.3) is therefore exceeded.

If one takes the probability value of $10^{-10}\ h^{-1}$ for each monitored or triple redundant block in Figure 4-80 including the power supply, the chances of failure in the vehicle control system leading to a situation in which an accident is possible is $13 \times 10^{-10}\ h^{-1}$. From these calculations, it follows that there is one chance for the occurence of an accident caused by a failure in

vehicle control every 200,000 years for each vehicle, when one considers an operational day of 10.4 h (see Section 4.10.3, Table 4-3).

4.9.7 Reaction to Recognized Component Failure

The planned monitors or comparators would detect all failures regardless of whether they are critical to safety or not. When a failure is detected it would be determined whether it belongs to category A (critical), or categories B, C, or D (uncritical). For example, it is important to recognize at which comparator a failure has been detected, and whether the input difference measured by the comparator is in a "safer" or "less safe" direction. Failure recognition in the vehicles should therefore consist of four separate levels, which would be reported to central control:

0. Vehicle is free of failures.
1. The vehicle can travel independently to a maintenance station in the presence of failure.
2. Vehicle stops, but remains towable or pushable.
3. Vehicle stops, and may not be towed or pushed.

This classification does not necessarily correspond to the failure categories A, B, C and D, which differ in the possible result of a given failure.

Categories 0, 1, 2, and 3 differ in the reactions taken by the safety equipment.

Examples of a category 1 situation are the failure of one element in a triple redundant central control unit (Figure 4-80), and malfunctions of the doors.

Category 2 includes malfunctions in the monitored safety critical components, such as transmitters and brakes.

Failures in category 3 would include a broken switching rod, or a broken switching wheel.

A coupling has been developed so that a vehicle which is malfunctioning, but is still movable (category 2), may be pushed or towed along the track using a special recovery vehicle (see Section 4.8.5). Such a vehicle may also be

pushed by a following vehicle. (This can not be accomplished in the event of drive power failure or presently at switches.)

The mechanical coupling needed for pushing is already functioning at the test track. The electrical coupling components needed for signal transfer (for example, to operate the headway control system and transfer of switching signals) are currently under development. It has been estimated that 120 such vehicle failures could occur each 10^6 hrs (see Table 4-4).

In the situation where the vehicle may not be pushed or towed (category 3), the vehicle would be accessed by a special vehicle designed for the system, or perhaps by a ground-based vehicle. If the malfunction requires some type of repair, the passengers could be transferred to another vehicle (Section 4.9.8.3).

4.9.8 Passenger Safety

4.9.8.1 Passive Safety Features

The extensive measures being planned, such as a redundant design for headway control, and special monitoring circuits for the automation equipment help to prevent accidents. However, risk still exists from poor workmanship, the failure of materials, or the consequence of some unforeseeable defect. Therefore, passive-type safety equipment has also been developed (or is now in development).

A front panel crash pad, combined with a special composite glass front windshield, lessens the effects of any collisions. In the unlikely case of a brick wall crash, this safety equipment should greatly reduce the possibility for any fatal injuries. Passive safety systems, such as safety belts and air bags have also been tested. The seats are formed so that passengers should remain in them even during high decelerations. These seats are equipped with head rests.

Various measures have been used to protect against fire. The primary method has been by the use of material, which is difficult to ignite and self-extinguishing, and by making the heating system inaccessible to passengers. In addition, a heat shield is planned between the passenger compartment and the bogie.

4.9.8.2 Passenger Options (in case of system failure)

In addition to the system reactions to operational malfunctions, the passengers also have the option for some initiative.

It is possible for a two-way radio intercom system to be installed for conversations between the vehicles and central control.

An emergency stop switch, with which the vehicle may be stopped along the track, has not been installed in the cabins. The use of such a stop handle has been avoided until there is some means available for passengers to leave the vehicles and walk along clear track sections to safety (safety ladders or guideway cat walk, etc.). Present planning calls for a pushbutton which will cause the vehicle to stop at the next station. It is estimated that the average trip time to the next station from any point on a normal network system is approx. 30 s. This appears to be a sufficiently short time.

4.9.8.3 Passenger Rescue

The recovery or rescue of passengers would be especially important in cases where a failed vehicle could not be pushed or towed along the guideway. One option for the recovery of passengers would be the use of ground-based recovery vehicles. This option, however, would not be possible on sections of the track which cross over rivers or deep valleys. A special vehicle has been designed for the system with independent propulsion (see Section 4.8.5). The failed vehicle may be approached either on the track which it occupies, or on an unblocked level of a double guideway. The recovery vehicle personnel are then capable of opening the door and recovering the vehicle's occupants, and if the situation permits, carrying out repairs. These vehicles could be positioned at different points along the network ready for use.

Another alternative is equipping the total length of the guideway with one or two permanently installed evacuation cat walks. The use of this option would require that the passengers be able to open the doors. Considerations of cost, aesthetics, and the possibility for misuse of such a walk way has led to the decision that the doors should remain closed until rescue personnel arrive on the scene. The passenger, however, does have the option of opening a ventilation door, by which under the worst circumstances, suffocation (in case of fire) might be avoided.

Should it become impossible to repair the damaged vehicle to the point where it may be pushed or towed along the track (malfunction category 2), a ground based crane would have to lift the vehicle from the track and transport it to the maintenance facility using available street facilities.

4.10 RELIABILITY AND AVAILABILITY

The many questions concerning reliability and availability as they apply to the various components of the vehicles, guideways, automation, etc., for all 3 variations of the Cabinrail system, will be discussed in this section. Discussions on subsystems apply to the 3-seat or 12-seat small cabins, as well as the Cabinlift system. The Cabinrail systems differ only in the way in which the various subsystems are configured and used. A specific example of a small network for which concrete plans have been made is given in Section 4.10.5.

4.10.1 Definitions

For this discussion, the following definitions will be adopted:

"Reliability" is defined as the probability that within a given time interval (for example within one hour, which may be translated to the time required for carrying out a particular transport assignment), no malfunction in the total system or in the subsystem under consideration will occur. It is a function of time.

"Failure Probability" is defined as the probability that within a given time interval, at least one malfunction in the total system or in the subsystems under consideration will occur. It is a term used to denote the opposite of reliability.

"Failure Frequency" is defined as the expected number of malfunctions in the total system or in the subsystems under consideration, within a time interval (for example, during one hour). It may be translated to give the number of transport assignments which will not be carried out within a time interval in accordance with a plan. Failure frequency could be time dependent.

"Mean Time Between Failure" (MTBF) is defined as the average time between a failure in the total system or in the subsystems being considered.

Following the preceding definitions, it can be seen that the reliability of a particular subsystem gives the proportion of the total time that the particular subsystem is in operation.

The term "availability" cannot be clearly defined. It carries different meanings under different situations. For example, in the case of vehicles, the term could simply be used to answer the question of whether or not it is operational - either, yes or no. On the other hand, the larger question of whether or not the total system is operational cannot be unambiguously answered with a simple yes or no. Such expressions as "more or less operational" or "operational with degraded performance" are used. In practice, the concept of availability must be tied to performance and service, and be related to the points of view of the user and the operator. The following definitions may apply:

> "Availability to the user" is the probability that the users' request for travel can be fulfilled within a certain given time.
>
> "Availability to the operator" is the probability that the expected number of travel requests can be fulfilled within a time interval acceptable to the passengers.

4.10.2 System Architecture and Availability

Despite careful selection of the components, fabrication procedures, and proper maintenance, some malfunctions will still occur. The system must be able to live with malfunctions. That is, even with malfunctions it should still remain available in accordance with the definitions contained in Section 4.10.1. In order to accomplish this goal, the Cabintaxi/Cabinlift control system has been designed with three hierachical levels (also see Section 4.2.1).

The first (lowest) level encompasses the vehicle automation and control of the merging switches. Both subsystems work autonomously. They do not depend on the proper functioning of higher automation levels for their operation. Redundancy is provided by a large number of identical vehicles. The failure of one vehicle has practically no effect on the availability of the total system.

Even when a track section is blocked, the total system, in general, should remain available through the use of detour options. The passengers should have the option, in the case of double rail, to change to the second level (top-mounted or suspended).

The second (middle) automation levels consist of the station control, control for the direction information at the branching switches, vehicle detectors along the track, and traffic data such as the vehicle stream, etc. Malfunction of this subsystem, in general, has little influence upon the total system. If a station control unit malfunctions, its assignment can, to a large extent, be taken over by a neighboring station. A defective direction control would perhaps allow a few vehicles to take the wrong branch at a demerging switch. This would automatically be corrected, however, at the following demerging switch, as it will be possible for the Cabinrail system to reach any desired destination from any given demerging switch. The result of such a malfunction would be detours and deteriorated service for a few passengers whose normal route included the defective direction control. Availability from the operators point of view would hardly be affected by such a malfunction. Malfunctions in the detectors for traffic data will give false input to the network computer concerning the actual traffic situation, (the network computer is part of the function third level automation.) However, these data will be compared with data received from neighboring detectors. The effects of such failures will be limited.

The third (highest) automation level consists of the network computer. In the case of large networks, the computer can itself be hierarchically constructed from several area processors and a central processor. The important assignments at this level consist of the management of empty cabins and the traffic flow control. Total failure of the network computer will result in a traffic flow controlled mainly by the dynamics characteristic of the vehicle platooning on the network, as well as the switches. As long as the vehicle platooning remains stable, there cannot be total failure. The total performance of the network, however, will be somewhat reduced. A similar situation applies

to the distribution and supply of empty cabins which, without the help of the system computer, will be carried out with reduced efficiency by the operation of the station computer. Failure of the network computer will, therefore, have a strong influence on system availability.

4.10.3 Reliability and Performance Analysis

In the process of developing system reliability, detailed performance analyses were carried out for all important subsystems. Beginning with the failure probability of the individual electronic and mechanical components, the malfunction probability and the mean time between failure (MTBF) of the important subsystems were theoretically calculated, and the effects of these malfunctions were investigated.

Based on the failure rates used in the space and satellite programs, an initial estimate of component reliability was obtained. This initial estimate took into consideration the effects of temperature influence, load factors, and the environmental conditions, such as vibration. For the most part, one of the lower quality classes of the MIL-HDBK-217B specification [22] was used. Therefore, the theoretical analysis was performed based on high failure rates. If the highest quality class of MIL-HDBK-217B were used, the calculated failure rate would be reduced on the average by a factor of 10.

Failures were classified into four categories (see also section 4.9.2):

- Category A - Possibility of an accident exists
- Category B - Serious system malfunction
- Category C - Minimal system malfunction
- Category D - Noncritical

The analysis was carried out first for simple systems for which no safety measures or redundancy provisions have been considered. An example of the results for a vehicle is given in Table 4-3 [21].

Table 4-3

FAILURE FREQUENCY OF A VEHICLE WITHOUT REDUNDANCY MONITORING

Malfunction Category	Failure Frequency During 10^6 h	MTBF in Days*
A	82.8	1160
B	39.8	2420
C	134.4	720
D	-	-
A+B+C+D	257.0	370

*Calculated: 1 day = 7 hours in motion + 0.2 x 17 stationary hours = 10.4 h

Next, analysis was carried out incorporating the redundancy and safety monitoring systems. All failures of category A were eliminated, and the failure frequency of category B was also reduced. The results of this analysis for the vehicles are given in Table 4-4 [21]. In this case, the concept of "not tow-able" as described in Section 4.9.7 does not apply since the failures which will result in the vehicle being untowable can only be mechanical defects, such as broken parts. Such types of failures are, for the most part, not included in theoretical probability considerations. For present purposes, malfunction items 2 and 3 are considered together as malfunctions resulting in the requirement that the vehicle be removed from the track section by means of power other than its own.

Table 4-4

FAILURE FREQUENCY OF A VEHICLE WITH REDUNDANCY AND MONITORING (COMPARE ALSO SECTION 4.9.3) DURING 10^6 OPERATIONAL HOURS, MTBF IN DAYS (1 DAY = 10.4 h)

Component Group	Total Failures (with Monitoring)	MTBF	Those Pushed or Towed	MTBF	Goes to Repair Facility Under Own Power	MTBF
1) Data transfer	10.2	9400	10.2	9400	0	
2) 2 receivers (cable) (together)	17.6	5500	8.8	10,900	8.8	10,900
3) 2 transmitters (cable) (together)	46.6	2100	21.0	4600	25.6	3800
4) Linear brakes with their control	18.2	5300	6.6	14,600	11.6	8300
5) Linear motors with their control	28.8	3300	14.4	6700	14.4	6700
6) Mechanical brake system	47.6	2000	37.6	2600	10.0	9600
7) 2 doors (together)	11.0	8700	0		11.0	8700
8) Cabin logic, lights, switching wheels	36.3	2600	3.6	26,700	32.7	2900
9) Central control unit	129.0	700	0	∞	129.0	700
10) Power supply	59.5	1600	18.8	5100	40.7	2400
Total	404.8 (100%)	240	121.0 (30%)	800	283.8 (70%)	340

Comparison of Tables 4-3 and 4-4 shows that the increase in safety gained by the introduction of redundancy and monitoring concepts must be paid for by a decrease in reliability. This is because of the larger number of functional channels which cause the overall failure frequency to increase.

If one considers the MTBF for a vehicle to be 240 days (from Table 4-4), then a complex facility having on the average 1,000 KKK3 vehicles, would expect about 4.2 vehicle failures during a given day.

The MTBF in Table 4-3 of 370 days (that is 370 x 10.4 = 3850 h) was a target value for the vehicles at the test facility, and will be compared in the next section to the reliability obtained in practice.

The theoretically calculated failure rate and the MTBF have not yet been achieved in practice. Testing at the Hagen Test Track has, up to this point, been done with vehicles having no redundance or monitoring equipment. Table 4-5 is a summary of the analytical results of other subsystems.

4.10.4 Failure Recognition and Historical Reliability Data

Aside from theoretical analysis, all failures which have occurred during the course of testing have been systematically noted on a special form (Figure 4-81). These failures were corrected either by immediate measures, such as

Table 4-5

FAILURE FREQUENCY OF OTHER SUBSYSTEMS

Subsystem	Failure Frequency During 10^6 h	MTBF In Days*
Demerging switch	93	447
Free merging switch	321	130
Station demerging switch	561	74
Station automation (double rail station)	1306	32

*In contrast to that for the vehicle, a day here =´ 24 h

Cabinentaxi
DEMAG·MBB

FAILURE FORMS

No.

Page of

Name of Malfunctioning Unit	System	Subsystem Main Component
Serial Number Service Number	MBB ☐ DFT ☐ Conz ☐ Manufacturer	Drawing No.

Description of Malfunction

Date/Time of Malfunction

Environment

Mode of Operation
- Handbetrieb ☐
- Handbetrieb mit D-System ☐
- Automatik ☐
- Wartung ☐
- Dauerversuch ☐
- ______ ☐

Suspected Cause of Malfunction:

Date | Name, Dept.

Measures Taken to Correct Malfunction:

Date | Name, Dept.

Results: Actual Cause of Malfunction, Measures

Analysis of Failures by the
Manufacturer and Contractor

Date | Name, Dept.

Possible effects on Operation
- Unkritisch ☐
- Geringfügige Betriebsstörung ☐
- Große Betriebsstörung ☐
- Unfall(gefahr) ☐
- ______ ☐

Decision
- Verwendbar ☐
- Nacharbeit ☐
- Nacharbeit mit Bauabweichg ☐
- Ausschuß ☐
- Neufertigung erforderlich ☐
- Zurück zum Hersteller ☐
- Zeichnungsänderung erford. ☐
- ______ ☐

Erledigt:

Datum Name, Abtlg.

Verteiler: DFT, JABG

Nach Ausfüllen an Produktsicherung

Verteiler
grün: Aussteller
rosa: Begleitpapier zum defekten Teil
Original und restl. Kopien an Qualitätssicherung

Figure 4-81. Failure Reporting Form

repairs, or longer term measures, such as design changes. A copy of every malfunction report was forwarded to the IABG. At regular intervals, these malfunction reports were examined to obtain statistics relative to the causes of failures. The failure types included:

- Weakness in development or design
- Failures in fabrication or adjustment
- Environmentally caused failures (corrosion from moisture or overloading, or tension from inclement weather, or the effects of temperature)
- Human error (for example, operational failures, measurement failures)
- Component and material failure
- Secondary failures resulting from an initial malfunction
- Accidents
- No failure (when a failure in the system was mistakenly assumed and reported)
- Undetermined

These failures were correlated to the distance traveled in the case of vehicles, to the number of tickets that have been purchased or processed in the case of station automats, and overall to the time in operation. Special attention was given to recurring or serious malfunctions.

As a comparison to the theoretically calculated failure frequency, Table 4-6 gives the number of malfunctions that have actually been experienced at the test facility with five suspended and three top-mounted cabins. The malfunctions reported for the vehicles were further broken down into categories of failures as shown in Table 4-7. Table 4-8 presents a time history of the occurrence of such failures.

It is seen from Table 4-8 that the environmentally caused failures have been sharply reduced over time through appropriate design improvements. The data also indicated that the MTBF was very good in the first evaluation time interval. However, this could be due to the fact that during this time the failure reporting and evaluating system was being introduced, and not all failures were reported. Disregarding this, the trend on MTBF does indicate improvement.

TABLE 4-6

NUMBER OF MALFUNCTIONS TO 3/15/77

In the vehicles		
Suspended	268	356
Top-mounted	88	
In the track system and switches	26	
In the station	19	

TABLE 4-7

CLASSIFICATION OF VEHICLE MALFUNCTIONS

	Suspended	Top-Mounted		Total
Development and design	93	26		119
Fabrication and adjustment	61	21	82	82
Environmental	17	3	20	20
Human error	21	8		29
Component or material failure	26	7		33
Secondary resultant failures	12	4		16
Accidents or similar situations	4	1		5
No failure	10	3		13
Undetermined (As of 4/25/1977)	24	15	39	39

Table 4-8

OCCURRENCE OF VEHICLE FAILURES DURING FOUR CONSECUTIVE TIME INTERVALS (WITHOUT REDUNDANCY AND MONITORING)

	Time Interval Evaluated I (to 10/10/75)	II (10/11/25 - 2/25/76)	III (2/26/76 - 7/23/76)	IV (7/24/76 3/15/77)
Development and design	30	25	26	38
Environmentally caused failures				
Water	7	2	1	1
Cold	-	7	2	-
Components and material	4	9	7	13
Time in travel (h)	2538	1284	1492	5893
Distance traveled (km)	24800	32,501	44,037	120,781
Detected developmental errors per 1000 km	12.1	7.7	5.9	3.1
Detected developmental errors per 1000 travel hours	11.8	19.5	17.4	6.4
Kilometers traveled per component failure	6200	3600	6300	9300
Hours traveled per component failure (MTBF)	653	143	213	453

However, the last value of 453 hours is still quite some way from the theoretical target of 3850 hours (Table 4-3) for vehicles without redundancy or monitoring systems. This large discrepancy may be caused by developmental shortcomings uncovered at the Hagen test facility which required changes in some of the theoretically calculated MTBF. A much better handle on system reliability can be expected from newly fabricated vehicles (e.g. for the Cabinlift facility for Bremen.)

Aside from cabin malfunctions, problems with the track elements, switches, and stations, have also been considered in detail, including a few developmental weaknesses which have been uncovered using the malfunction reporting forms, and steps have been taken to correct them. However, no evaluation for

the length of the malfunction in time is available. Hence, no statement can be made with regard to the mean time to restore (MTTR).

As a further example, Table 4-9 gives the malfunction statistics of the second generation station automats where the development or design failures have been practically eliminated. The component and material failures are very close to the theoretical calculated values (see Section 4.10.3, Table 4-5).

4.10.5 Vehicle Availability of a Cabinrail Network

It should be apparent from the definitions in Section 4.10.1 that the determination of the availability of a Cabinrail network is extremely difficult. Availability is dependent on, among other things, the network structure, the network geometry (length of the clear track sections between two switches), and the division of the traffic load on the network (traffic concentrations along small track sections or average number of vehicles on a track section between two switches). This data, in general, can be obtained in advance only by dynamic simulation of the entire network (see Section 4.13).

Table 4-9

FAILURES IN THE STATION AUTOMATS

	Evaluation Interval				
	I	II	III	IV	Total Time
Total malfunction of which	7	7	1	4	19
Environmentally caused	3	-	1	1	5
Component and material failure	4	6	-	3	13
Operational hours	2700 (always 2 stations)	2875	2500 (always 1 station)	4800	18,400
Theoretically predicted component failure	7.1	7.4	3.3	6.3	24.0

In order to provide some typical values, an example will be given based on a specific Cabinrail network with KK3 cabins, which was used in a feasibility study for Marl [26]. This network was the H 2 variant (see Section 4.12). The theoretically calculated number of vehicles which would be halted each hour because of a malfunction aboard that vehicle, or because of a malfunction aboard another vehicle was calculated. All other vehicles which were sufficiently close behind either the defective vehicle or a defective switch so that they could not select an alternative route, were counted as halted vehicles.

Table 4-10 gives the network data for the system planned for Marl, (Network variation H 2).

The probability of a vehicle malfunction which will result in the halting of the vehicle, is assumed to be $\lambda_F = 121 \cdot 10^{-6}\ h^{-1}$ (see Table 4-4, those pushed or towed). The probability of a switch malfunction which will lead to a temporary vehicle halt is, according to estimates of the manufacturer, $\lambda_W = 20 \cdot 10^{-6}\ h^{-1}$. Also, a track section blockage due to a stationary vehicle

Table 4-10

NETWORK DATA FOR THE SYSTEM PLANNED FOR MARL
(NETWORK VARIATION H 2)

Number of track sections (that is, between switches)	T	75
Number of stations	S	62
Number of free merging switches	V	25
Number of free demerging switches	E (=V)	25
Number of network switches	W = V + E	50
Number of vehicles (empty or occupied vehicles)	N	
Level 1		767
Level 2		793
Average number of vehicles on each track section	$n = \frac{N}{T}$	
Level 1		10.23
Level 2		10.57

will cause an average of $\frac{n}{2}$ vehicles to halt. Hence, malfunction of a demerging switch would cause n vehicles to stop, whereas malfunction in a merging switch would cause 2n vehicles to stop.

Using the information above, the number of vehicles which will be halted each hour because of some defect can be calculated.

The result is given in Table 4-11. Since these numbers were computed by assuming that all vehicles are on the network at the same time, the results are valid only for peak hour travel. During the non-peak hours, the number of malfunctions would be correspondingly reduced.

Table 4-11

NUMBER OF VEHICLES WHICH WILL BE STOPPED EACH HOUR BY VEHICLE OR SWITCH DEFECTS ON THE PLANNED MARL NETWORK (NETWORK VARIATION H 2)

	Level 1	Level 2	
Stopped each hour because of vehicle defects	0.47	0.51	vehicles
Stopped each hour because of switch defects	0.02	0.02	vehicles
Total	0.49	0.53	vehicles

4.11 THEORETICAL SYSTEM PERFORMANCE

In this section the performance of the

- Cabintaxi KK3
- Cabintaxi KK12
- Cabinlift

systems, as used for scheduled route travel as well as discretionary specific destination travel, will be discussed (KK3 is only planned for discretionary specific destination travel).

The performance data will be expressed through analytical calculations in terms of operational performance (vehicles/h), and transportation performance (passengers/h).

The results are theoretical maximum capacities, based upon the given premises, which do not consider the circumstances which may be found in a real-life network. Actual load on a track section of the network will be influenced by factors which have not been investigated here, such as the number of occupied vehicles, waiting time of the passengers, etc. Comments with regard to these factors will be possible later, after practical operation. At the present time, realistic conditions may be illustrated by dynamic simulation (see Section 4.13).

4.11.1 Discretionary Traffic to Specific Destination (demand mode)

The performance will be evaluated for the following system area

- Track sections
- Merging switches and
- Stations

The interaction of these components on an actual network allows the system performance to be determined.

4.11.1.1 Performance on Clear Track Sections

Operational Load (vehicles/h)

For the determination of the track section performance, the track characteristics with respect to a static column is determinate. (That is, a column of vehicles at uniform speed with uniform interval.)

The performance may be expressed as:

$$Q_S = \frac{v \cdot 3600}{d_{stat(v)}}$$

where:

v = speed

$d_{stat(v)} = a_0 + a_1 \cdot v + a_2 \cdot v^2 + a_3 \cdot v^3$ (see Section 4.2.2.1)

Computer simulation by the manufacturer has yielded concrete values for the constant parameters in the headway algorithm [27] for the KK3 and KK12 Cabintaxi systems. Accordingly, a_0 = 2.8 m (KK3) and 5.6 m (KK12) = interval of vehicles when stationary

$a_1 = 1.1$;

$a_2 = 0$;

$a_3 = 0.0012$

These values are based on an operational speed of v = 10 m/s, and an average emergency deceleration of b_N = const = 5.1 m/s^2 (according to the manufacturer these values hold for V > 2 m/s). These values are within the planned revision to BOStrab recommendations for vehicles equipped only with seating positions (planned average max. acceleration of b_N = 6.0 m/s^2). Emergency braking acceleration would only occur in unusual operational circumstances. In normal operation, braking is accomplished with the normal operational deceleration.

Figure 4-82 gives the results of these calculations up to the max. performance at $\dot{v}$ = 10 m/s. If some other max. speed should be selected, the function d(v) must be redetermined. The capacity curves will be modified with a change in selected speed.

Since similar investigations for the Cabinlift system are not yet available, the performance has been calculated by an approx. formula according to Section 4.2.2.1.

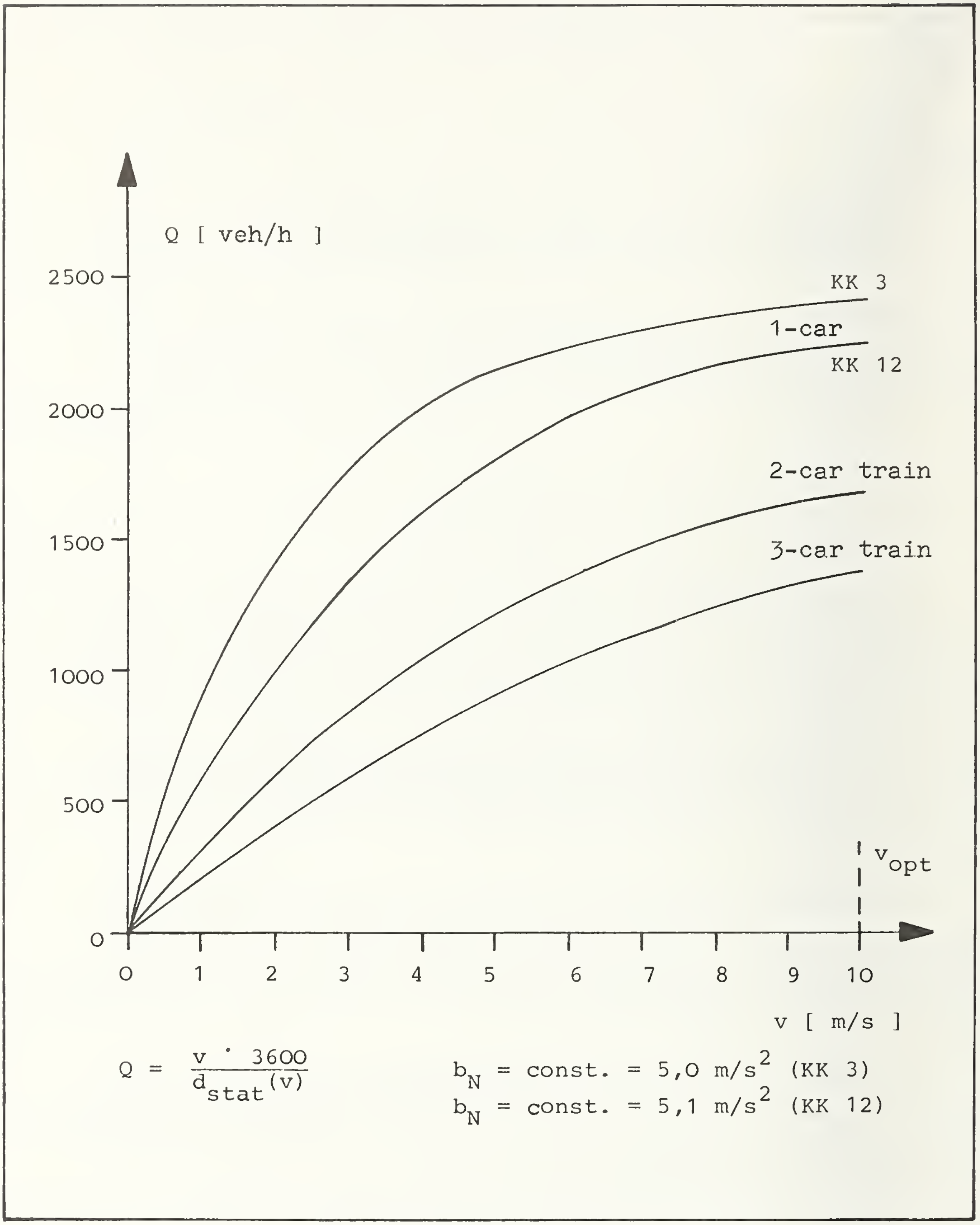


Figure 4-82. Capacity for Through Tracks (Cabintaxi)

$$Q_s = \frac{v \cdot 3600}{a_0 + v \cdot t_f + x_N}$$

where:

v = speed

a_0 = Interval of vehicles when stationary

t_f = Response time of the brakes

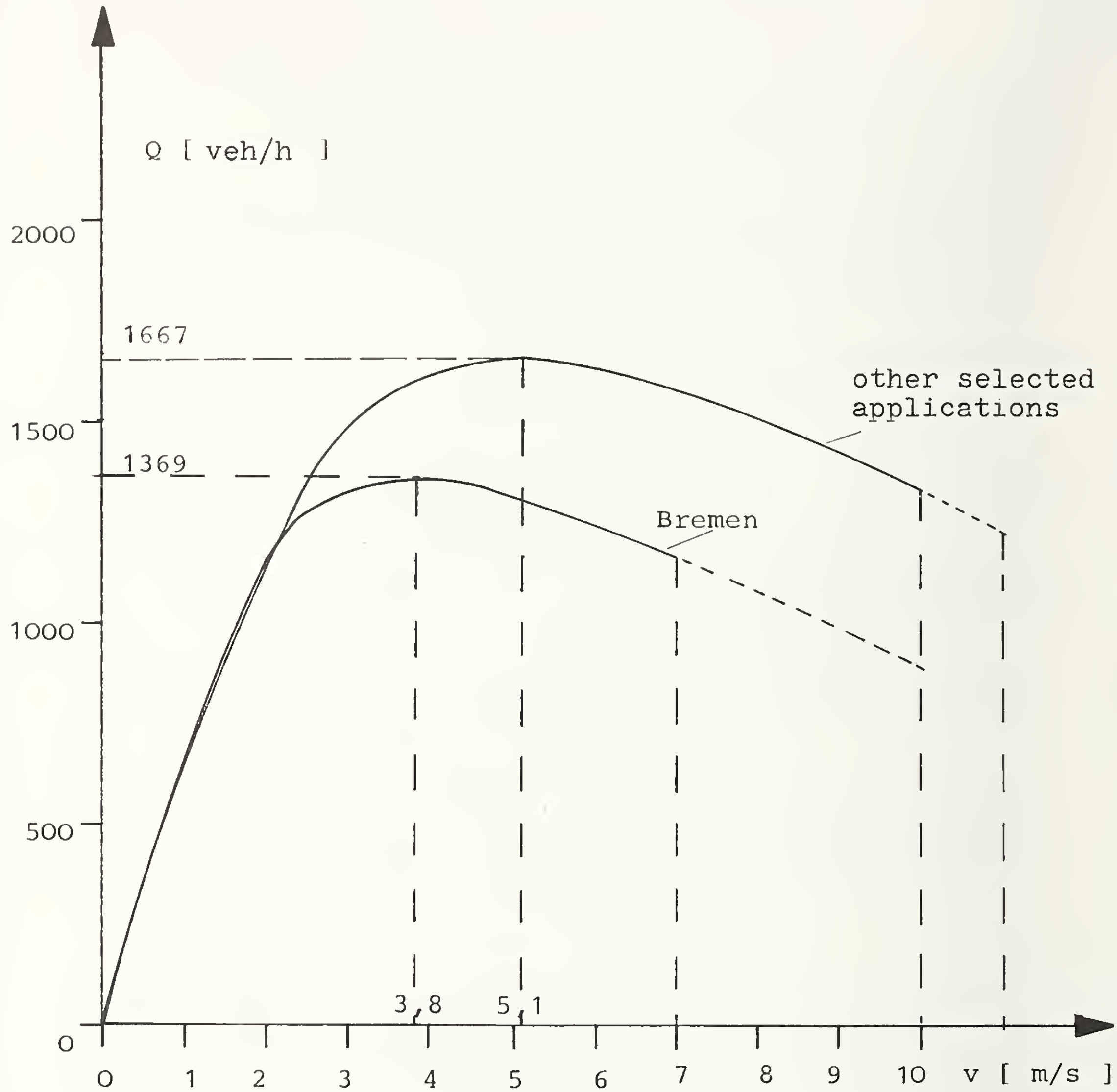
x_N = Emergency braking path, $x_N = \frac{v^2}{2b_N}$, whereby b_N is equal to the mean emergengy braking deceleration.

The track section performance (Figure 4-83) is given by the parameters $t_f = 0.1$ s, $a_0 = 4.8$ m (Cabinlift Bremen), or $a_0 = 5.3$ m (Cabinlift in general) and $b_N = 1.5$ m/s^2 (Cabinlift Bremen), or $b_N = 2.5$ m/s^2 Cabinlift in general). The curves show that the optimal speed is somewhat below the operational speed of v = 7 m/s (or 11 m/s). That is, the maximum capacity is at a speed lower than the maximum operational speed, in other words, reducing the speed increases the capacity on the track section.

Cabinlift Bremen	v = 7 m/s	Q_{10} = 1154 vehicle/h
	v_{opt} = 3.8 m/s	Q_{max} = 1369 vehicle/h
Cabinlift general		
Cabinlift general	v = 11 m/s	Q_{11} = 1244 vehicle/h
	v_{opt} = 5.1 m/s	Q_{max} = 1667 vehicle/h

The track section performance figures calculated here (Figures 4-82 and 4-83) could also be applied to discretionary traffic (off-line stations) on the through track, or when available, on branch or feeder lines, as well as track sections between on-line stations. The number of vehicles calculated here are to be seen as absolute maximum values, which may only be achieved over a short time interval. Over a longer time period, one must consider that individual vehicles in the column may vary somewhat from their assigned speed.

If one considers that the mean deviation of all vehicles from the assigned speed will be ± 0.3 m/s, the result is a small decrease in performance. According to reference [28] this deterioration is between 3 percent and 4 percent.



$$Q = \frac{v \cdot 3600}{a_o + v \cdot t_f + x_N}$$

b_N = const. = 1,5 m/s^2 (Bremen)

b_N = const. = 2,5 m/s^2

Figure 4-83. Capacity for Through Track (Cabinlift)

Traffic Load (passengers/h)

The track section performance (in passengers/h per direction) may be calculated from the operational loading with consideration given to occupancy. For the Cabintaxi system, the load factor is dependent upon the occupancy of the vehicles, and on the number of empty vehicles on a given track section.

Figure 4-84 shows the passengers/h for the small cabin KK3 as it relates to occupancy and the number of empty cabins, assuming a slightly decreased overall performance, as mentioned earlier. It must be the task of the cabin dispatching components to keep the number of empty cabins as low as possible on highly loaded track sections, in order to allow maximum passenger transport on these sections.

For example, if 20 percent of the cabins are empty this gives a track section performance of

$$Q_{10} = 1853 \text{ to } 2223 \text{ passengers/h and direction}$$

with an occupancy of between 1.0 and 1.2 passengers/vehicle.

With the KK12 system one can hardly differentiate between vehicles in use and vehicles not in use, since these vehicles hardly ever travel completely empty.

4.11.1.2 Vehicle Merging

The way in which a vehicle stream Q_1 merges itself with another vehicle stream Q_2 through a merging switch (see Section 4.2.3) is determined by the size of the two vehicle streams.

It is shown in reference [29] that the virtual image range switch causes no reduction in track section capacity when it is over-loaded, but that the outgoing traffic stream Q_3 after merging, is equal to the maximum section capacity Q_{max} (Section 4.11.1.1). Vehicles backed up before the switch do not come to a half, but reduce their speed to a value which is greater than or equal to the speed at which half the maximum track section capacity would be achieved.

The two merging traffic streams are assigned capacity and speed Q_1, v_1, and Q_2, v_2, when they are a long distance from the switching point. The

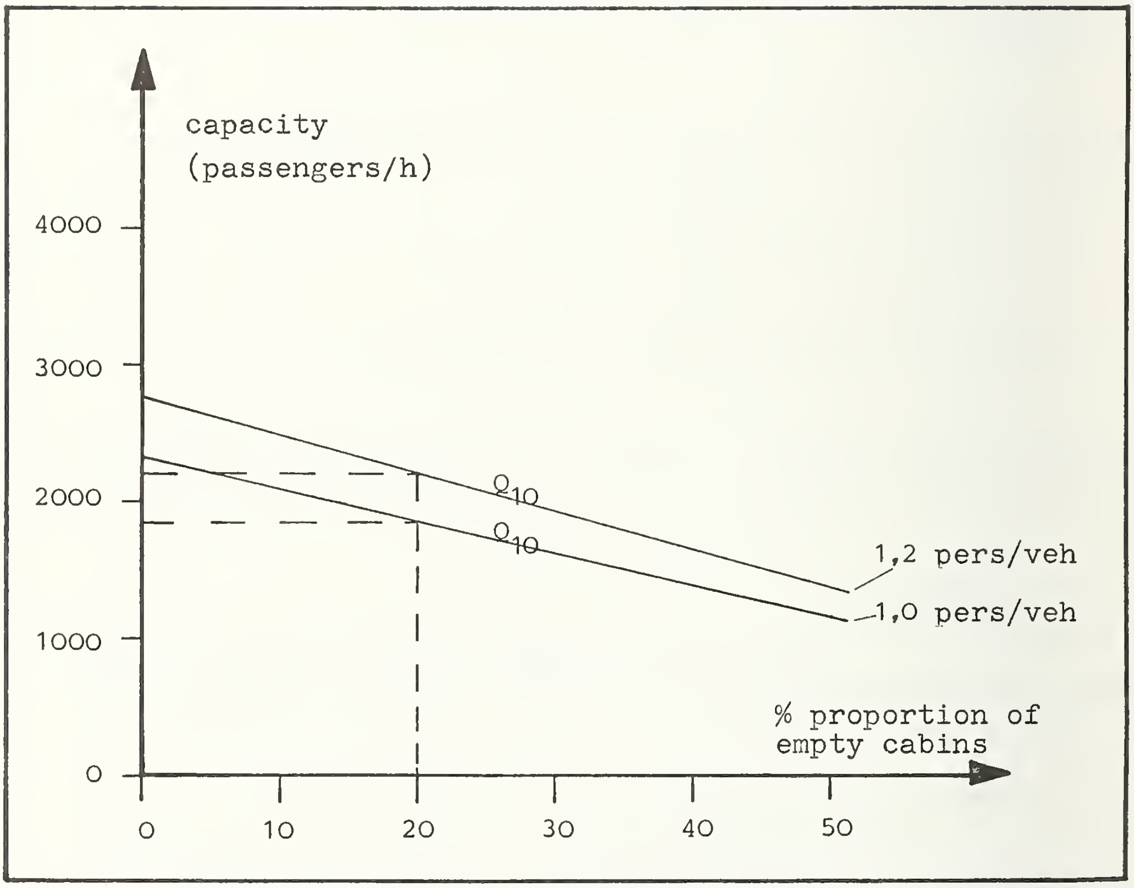


Figure 4-84. Capacity of Cabintaxi KK3 (pass./h) as a Function of Vehicle Occupancy Level and the Proportion of Empty Vehicles

approaching column can be either thick or thin (Q_1 and Q_2), i.e., equal to or less than the max. capacity appropriate to the speeds, v_1 and v_2. (See Figure 4-85.)

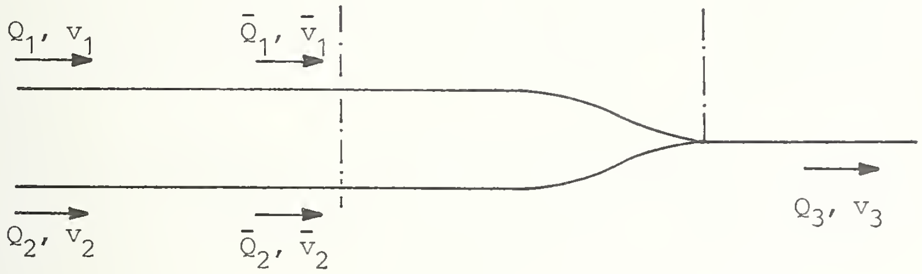


Figure 4-85. Designation of the Vehicle Stream at the Switch

For the outgoing (merged) vehicle stream:

$$Q_3 = \text{Minimum } (Q_1 + Q_2, Q_{max})$$

Q_3 is equal to the smaller of the two values $Q_1 + Q_2$ and

$$Q_{max} \quad \begin{matrix} Q_{v10} & \text{Cabintaxi} \\ Q_{vopt} & \text{Cabinlift} \end{matrix}$$

A clearly definable post merging speed v_3, can only be determined at a large distance from the switch, since in the switch area the switch negotiation speed is adjusted. The limiting value for v_3 is $v_{3,\infty} = v(Q_3)$.

In the neighborhood of the switches, the two on-coming vehicle streams adjust their capacity and speed to the values $\bar{Q}_1$, $\bar{v}_1$ and $\bar{Q}_2$, $\bar{v}_2$. The relationship $\bar{Q}_1 + \bar{Q}_2 = Q_3$ must hold, since the two vehicle streams are correlated with one another by the virtual image range, and therefore, may not travel at different speeds. That is: $\bar{v}_1 = \bar{v}_2 = \bar{v}$.

The scheme for calculating the values Q_3, $\bar{Q}_1$, $\bar{Q}_2$, and $\bar{v}$ for the Cabintaxi KK3 and KK12 considers four different cases:

Given:

$Q_1,\ Q_2;\ v_1 = v_2 = 10$ m/s is assumed:

A $\quad \underline{Q_1 + Q_2 > Q_{max}} \longrightarrow Q_3 = Q_{max}$

1 $\quad \frac{1}{2} Q_{max} < Q_1$ and $\frac{1}{2} Q_{max} < Q_2$:

$$\overline{Q}_1 = \overline{Q}_2 = \frac{1}{2} Q_{max};\ \overline{v} = v\ (\frac{1}{2} Q_{max})$$

2 $\quad \frac{1}{2} Q_{max} < Q_1$ and $Q_2 \leq \frac{1}{2} Q_{max}$

$$\overline{Q}_1 = Q_3 - Q_2;\ \overline{Q}_2 = Q_2;\ \overline{v} = v(\overline{Q}_1) < \begin{matrix} v_{10} & \text{(Cabintaxi)} \\ v_{opt} & \text{(Cabinlift)} \end{matrix}$$

3 $\quad Q_1 \leq \frac{1}{2} Q_{max}$ and $\frac{1}{2} Q_{max} < Q_2$

$$\overline{Q}_1 = Q_1;\ \overline{Q}_2 = Q_3 - Q_1;\ v = \overline{v}(Q_2) < \begin{matrix} v_{10} & \text{(Cabintaxi)} \\ v_{opt} & \text{(Cabinlift)} \end{matrix}$$

B $\quad \underline{Q_1 + Q_2 < Q_{max}} \longrightarrow Q_3 = Q_1 + Q_2$

4 $\quad Q_1 + Q_2 \leq Q_{10},$

Then:

$$Q_3 = Q_1 + Q_2;\ \overline{Q}_1 = Q_1;\ \overline{Q}_2 = Q_2;\ \overline{v} = 10 \text{ m/s}$$

Since the maximum for the track section performance for the Cabinlift is somewhat below the operational (= maximum) speed by these calculations, the calculation scheme for the Cabinlift must be augmented.

In addition:

5 $\quad Q_{10} < Q_1 + Q_2 \leq Q_{max}$

Then:

$$Q_3 = Q_1 + Q_2;\ \overline{Q}_1 = Q_1;\ \overline{Q}_2 = Q_2;\ \overline{v} = v\ (Q_3) \geq v_{opt}$$

Figures 4-86 and 4-87 present a graphic procedure for determination of switch capacity.

In the Q_1-Q_2 level, top right, the ranges 1 - 4 (Cabintaxi), and 1 - 5 (Cabinlift) are shown which are valid for the mode of calculation. To the left and underneath this graph, the capacity curve Q (v) from Figures 4-82 and 4-83 is drawn.

If Q_1 and Q_2 are given, one then determines the correct value by going to the line above and to the right, or point (Q_1, Q_2). Depending upon which of the 4 (or 5) areas, 1 - 4 or 5 the point is found, the formulas given for Q_3, $\overline{Q}_1$, $\overline{Q}_2$, $\overline{v}$, and $v_{3,\infty}$ are used to calculate the proper value.

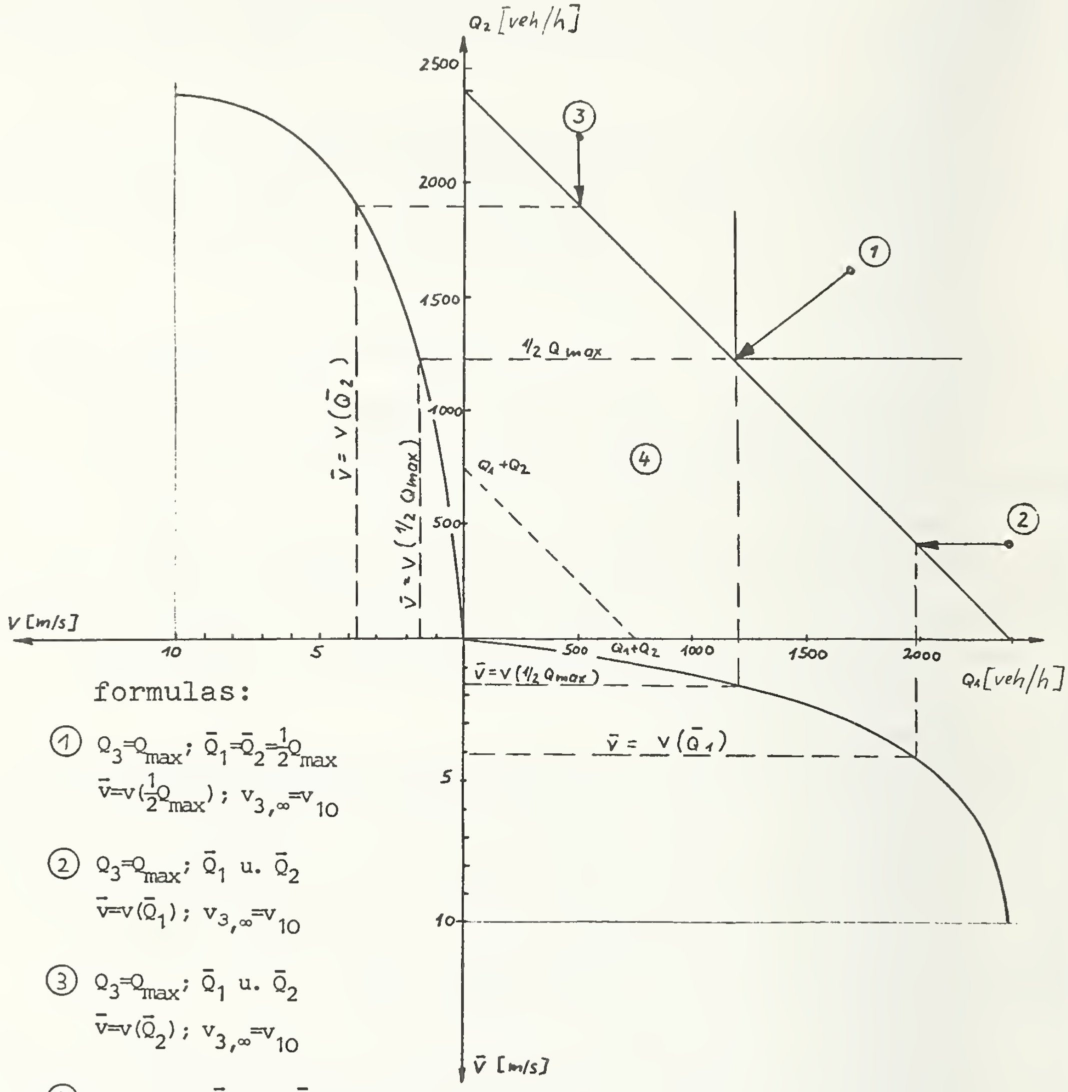
An important characteristic of the merging switches is especially apparent from this type of graphic representation. That is, whenever the switch is acting as a throttle, since $Q_1 + Q_2 > Q_{max}$, the weaker of the two vehicle streams Q_1 and Q_2 obtains preference. In the 2 and 3 ranges, the throttling effect is done completely at the cost of the heavier vehicle streams; the lighter vehicle stream goes completely through the switch (horizontal and vertical lines in 2 and 3). In range 1 both streams are reduced to $\frac{1}{2}$ Q_{max}, the heavier stream again suffering more reduction than the weaker stream.

4.11.1.3 Capacity of Stations

Depending on the situation, the bottle neck in a station will be either at the boarding platform, or on the remerging switch which connects departing vehicles with the main track. The required capacity at the station exit is given by the sum of the through-going vehicles plus the number of vehicles using the station. The capacity on an off-line track must therefore be considered independent of possible backups at the merging switch.

The theoretical capacity of an off-line track can be determined by analytical calculation procedures [2,30]. Results of simulation carried out by the manufacturers will be considered for the KK3 vehicle (2). These findings are based on the following assumptions:

- Boarding and deboarding only on off-line tracks.
- There is always enough passenger demand.



formulas:

① $Q_3=Q_{max}$; $\bar{Q}_1=\bar{Q}_2=\frac{1}{2}Q_{max}$

$\bar{v}=v(\frac{1}{2}Q_{max})$; $v_{3,\infty}=v_{10}$

② $Q_3=Q_{max}$; $\bar{Q}_1$ u. $\bar{Q}_2$

$\bar{v}=v(\bar{Q}_1)$; $v_{3,\infty}=v_{10}$

③ $Q_3=Q_{max}$; $\bar{Q}_1$ u. $\bar{Q}_2$

$\bar{v}=v(\bar{Q}_2)$; $v_{3,\infty}=v_{10}$

④ $Q_3=Q_1+Q_2$; $\bar{Q}_1=Q_1$; $\bar{Q}_2=Q_2$

$\bar{v}=v_{3,\infty}=10$ m/s

Figure 4-86. Cabintaxi KK3: Scheme to Determine the Switch Capacity and the Minimal Speed from Q_1 and Q_2.

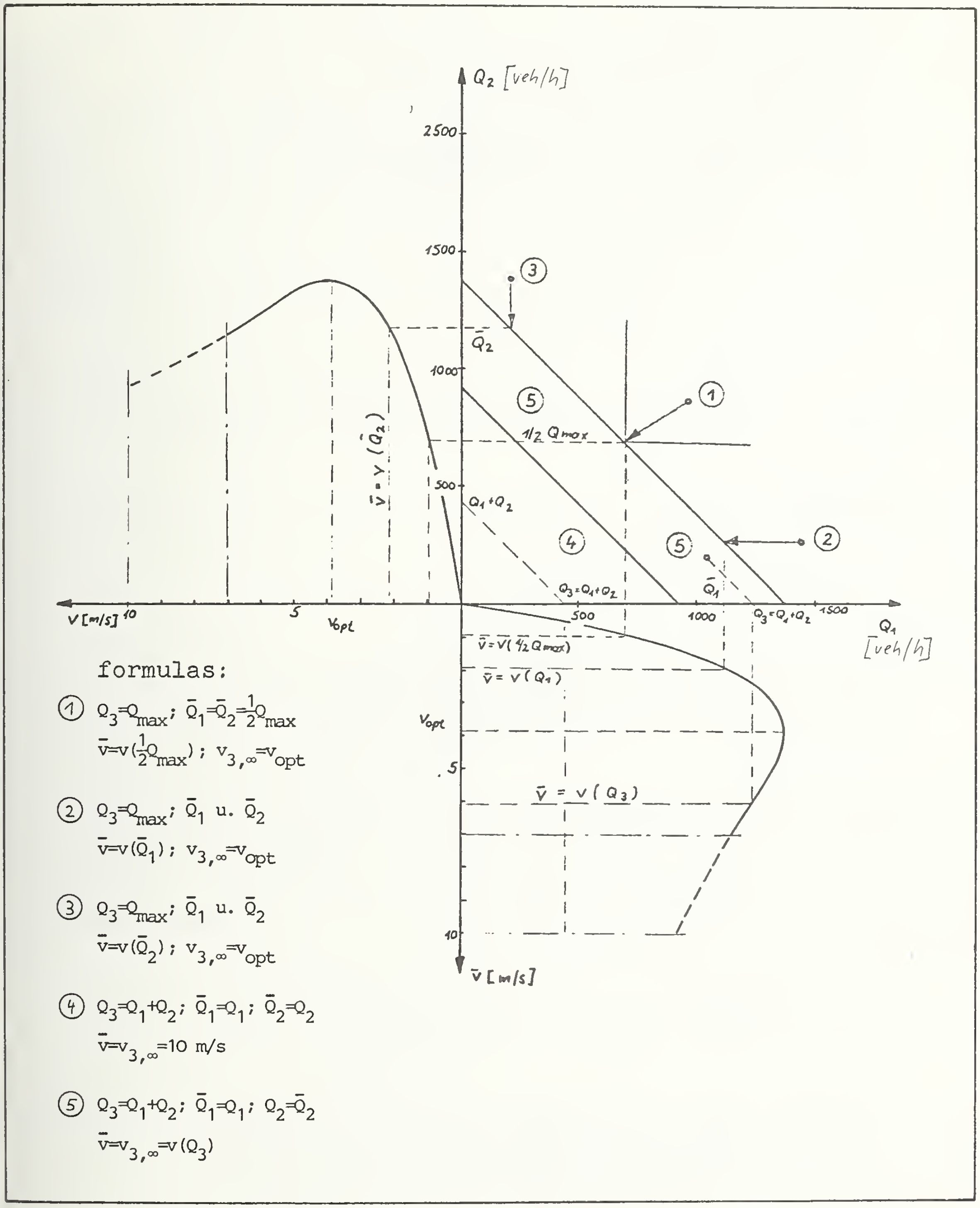


Figure 4-87. Cabinlift Bremen: Scheme to Determine the Switch Capacity and the Minimal Speed to Q_1 and Q_2

- Unhindered departure from the station, that is, no backups or hinderances from the merging switch at the exit.
- No waiting time is imposed on cabins which are ready for departure because of central vehicle dispatching. For consideration of waiting times the information in reference [31] should be consulted.

In references [2, 30], furthermore, the following requirement is set forth:

- The approach of k vehicles (bunched together) onto the off-line track (k - number of boarding points.)

The results of simulations carried out by the manufacturer for the KK3 cabin, in contrast to this, assumed a stochastic approach of the vehicles.

Cabintaxi KK3

In Figure 4-88 the results of simulations carried out by the manufacturer are shown.

The parameters shown in this illustration are:

p = mean occupation of the cabins in number of passengers, and

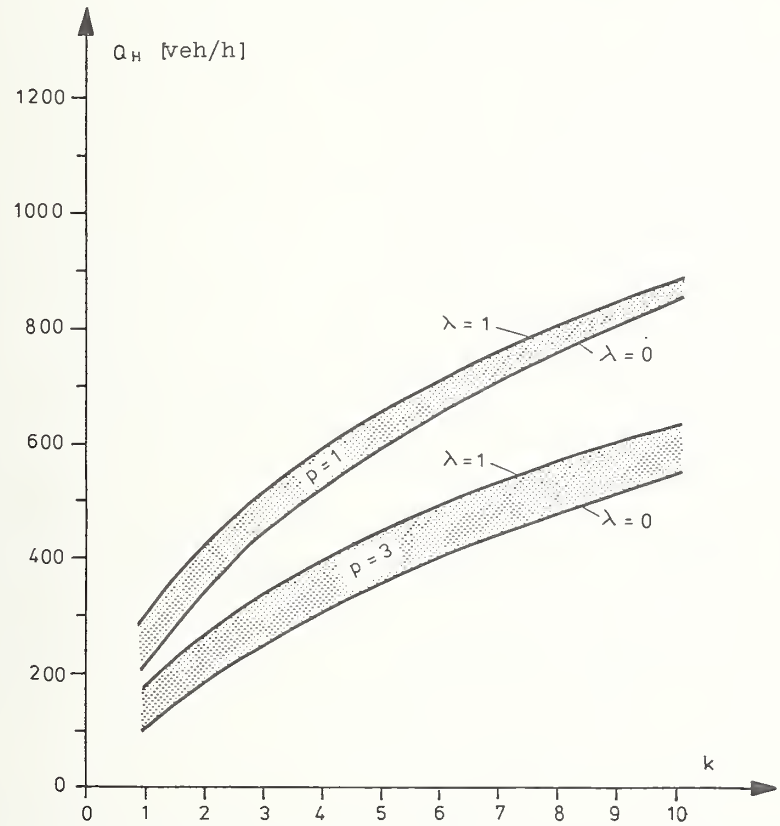
λ = ratio of the empty to the occupied cabins, which travel over the off-line track.

Both parameters influence the mean stopping time on the off-line track. The mean time for boarding and deboarding increases with increasing occupancy of the vehicles; the contribution of empty vehicles is to lower this mean stopping time since empty vehicles required no time for boarding and deboarding of passengers.

The curves assume the operational time required for passenger groups of p = 1 and p = 3.

The occupancy levels for the cabins are based to this point on measurements made from the load factor of normal taxis. In the Hanover, West Germany area, taxis carry on the average 1.35 passengers per vehicle [32].

vehicle length including safety measures	d_0 = 2,5 m
elapsed time before operation of brakes	t_f = 0,1 s
emergency braking deceleration to stopping point	b_{NH} = 2 m/s^2
operational deceleration to the stopping point	b_{BH} = 1 m/s^2
maximum speed at the station	v_H = 1,5 m/s



$\lambda = \frac{\text{empty vehicles}}{\text{total number of veh.}}$ $\lambda = 1$ all veh. are empty; $\lambda = 0$ all veh. are occupied

$p = \frac{\text{passengers}}{\text{occupied vehicles}}$

Cabin taxi KK 3

Vehicle conveyances (veh/h) Q_H for the station as a function of the number of boarding points k, occupancy p, and proportion of empty vehicles

Figure 4-88. Cabintaxi (KK3)

Cabintaxi KK12

The capacity using the KK12 vehicle is calculated according to reference [2]. The following formula for the minimum vehicle interval t_{min}, and/or the maximum number of vehicles is given

$$t_{min} = \frac{a}{v_H} + t_r + \frac{v_H}{2b_{NH}} + \frac{1}{k} \left(\frac{v_H}{b_{bH}} + t_H\right)$$

$$M_{max} = \frac{3600}{t_{min}} \frac{\text{VEH.}}{\text{h}}, \quad (t_{min} \text{ in s})$$

Assumptions for the calculation:

Speed in the station area:	$v_H = 1.5$ m/s
Mean acceleration and/or deceleration in the station area:	$b_{bH} = 1$ m/s^2
Docking point length:	$a = 5.0$ m[1)]
Mean emergency deceleration in the station area:	$b_{NH} = 2$ m/s^2
Response time of the control system:	$t_r = 0.1$ s
Number of docking points:	k

The mean stopping time of the cabins on the platform t_H is dependent, among other things, upon the occupancy and the number of docking points on the off-line track.

The capacity performance is illustrated as a curve with the stopping time as a parameter (Figure 4-89). On the second scale, the traffic over a station platform in passengers per hour is given for various levels of vehicle usage.

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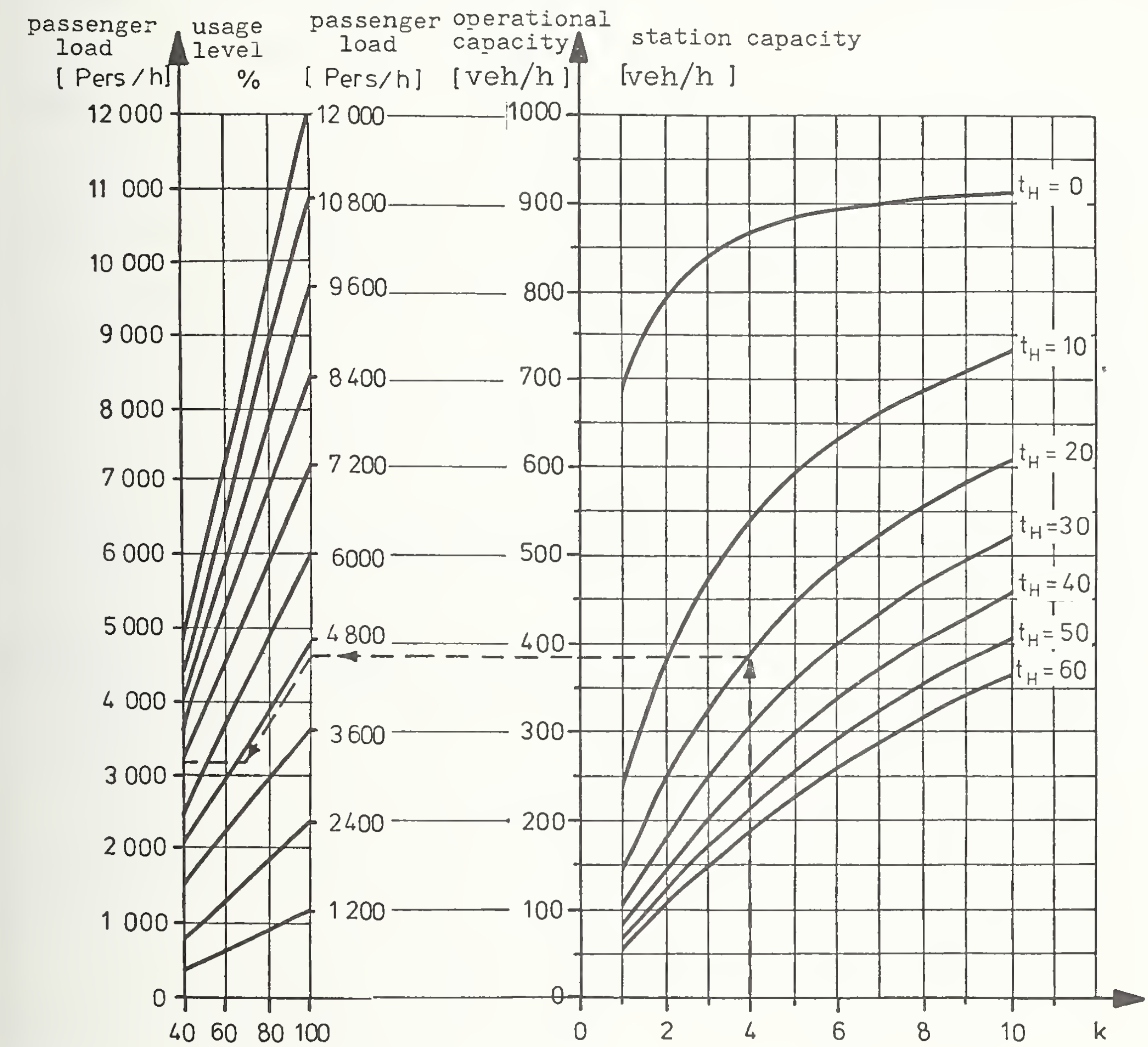
1) In contrast to the docking point length of 5.6 m which is given, this calculation is based on a length of 5.0 m.



EXAMPLE:

K = 4, t_H = 20 sec.,
usage level = 70%
passenger load = 3,200 pers/h

Cabin taxi KK 12

Figure 4-89. Station Capacity of an Off-Line Track with K Stopping Points as a Function of the Dwell Time t_h (seconds) from Reference 2

4.11.2 Line Operation with On-Line Stations

Normal line operation is especially relevant to the KK12 Cabintaxi (12-seat), and the Cabinlift. Investigations as to the performance capacity of Cabinlifts have recently been carried out using simulation. For the KK12 vehicle, aside from simulation results (Section 4-13), analytical calculations for an estimate of the capacity in on-line operation are available.

The schedule-controlled line operation adjusts its total capacity according to the time interval between arriving vehicles, which is allowed by the on-line stations. The headway control (interval holding) system of the Cabintaxi (see Section 4.2.2.1) can be applied. The time interval has been checked by the manufacturer considering that halt times (stopping times) would be between 17 and 27 seconds. This time interval was then checked using calculations relating to vehicle behavior in a backup situation. It is assumed that the on-line station has the capacity for handling two units (either single vehicles or a two car train). (This is dependent upon the platform length.) From this, it follows that the time interval can be equal to the smallest stop time, i.e., 17 seconds. Values gained from experience would give some idea as to the size of the tolerances for these calculations, which must be applied to actual operation. However, none were available for these calculations. An additional 6-8 seconds per stop is assumed by the manufacturer to be a realistic estimate. If one assumes a stop time of 20 seconds, it appears as if a vehicle interval along the line of 28 seconds would be possible. The interval time is assumed by the manufacturer to be realistic for longer trains as well.

The following performance capacity figures are therefore presented for on-line traffic:

	Seats per hour and direction
Single car	1500
Two car train	3000
Three car train	4500

4.12 NETWORK CONFIGURATION

The Cabintaxi and Cabinlift systems should be considered with respect to specific areas of application, as has been described in Section 3.4

The various transportation tasks require specific operational modes (Sections 3.4 and 4.1.1), and these must also be considered when the network is configured. Generally, valid basic principles for planning the network will therefore be presented, considering special circumstances encountered in the several individual operational formats.

4.12.1 Fundamentals of Network Planning

GENERALITIES

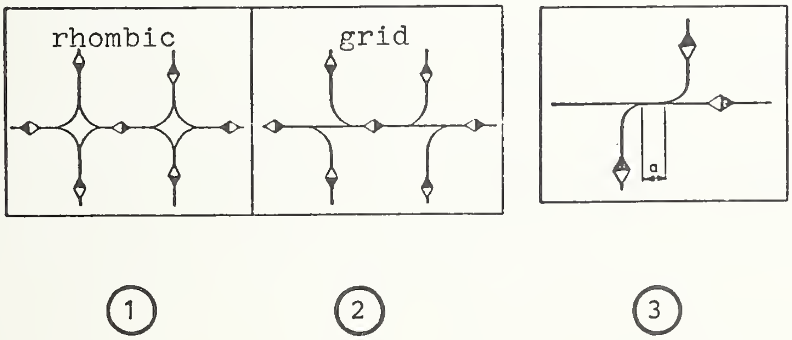
The principle used in the Cabintaxi and Cabinlift systems of having both directions of travel occur on a single dual-level guideway, with vehicles which travel around the network only in one direction on a given track, requires special network configurations. A changeover between the vertically separated tracks is not possible. On the two travel levels, therefore, two independent single-direction traffic streams are created. Basically, the system is made up of two closed, single direction loops. The same basic considerations apply in the planning of networks which have only a single track (for example, the Cabinlift). Generally, however, only sections of a Cabinrail network would be equipped with single track, which would serve to supplement the basic concept of the double track design.

FORMATION OF JUNCTION POINTS

The crossing of tracks on the same level is not possible. Similarly, for technical reasons, three or more tracks cannot be merged at a single point.

Merging points or junctions built on several levels were avoided because of their inefficient characteristics. Crossings, therefore, in principle are replaced by sequential merging and demerging points.

The following possibilities present themselves for the design of the four-arm junction point.



For a rhombic junction, four switches are required (grid junction: two switches); the area requirement is relatively large.

If the cross over point is located before a branch point, then for all practical purposes a track crossing is created (junction 3).

Between the V-points in the switches, a track length "a" (Section 4.4) is allowed for the response time of branching switch operations aboard the vehicle, so that the junctions, because of space and track layout considerations, are only usable in special cases in the sense of a street crossing. This design is more suitable when the appropriate street grid is available.

EVALUATION AND SELECTION OF NETWORK ALTERNATIVES

During the course of many application studies on the Cabinrail System, several alternatives were subjected to a more or less exhaustive evaluation for determination of the most suitable network configuration.

Evaluation and improvement was accomplished from transport, operational, economical, and urban architectural viewpoints. For evaluation, among other things, a catalog with evaluation criteria, cost efficiency considerations (for example, for determination of the level of cabin service in outlying areas) and dynamic simulation (Section 4.13) can be applied. Exhaustive investigation on this subject has been carried out in the form of feasibility studies [4], and [26] (Section 8.3).

In the Marl feasibility study, for example, a stepwise process of evaluation, selection, and improvement of network alternatives took place. In the first evaluation step, the selection of the basic network configuration was made based on the criteria of service area, operation, and network usage.

The same criteria are also used for evaluation in the second and third stages. In the second stage, the already determined basic form of the network and additional analysis of the effects of changes in parts of the track layout are considered. On the basis of knowledge gained, further network alternatives from the view of urban architecture and the possibility for the use of some sections of single direction track (i.e., either suspended or supported) are investigated.

After determination of a few additional network alternatives, the operation of the proposed network would be evaluated and optimized (Section 4.13) using dynamic operational simulation.

CRITERIA FOR NETWORK EVALUATION

In the following, criteria will be listed which may be used for evaluation of networks independent of the planned operational form. Further evaluation criteria which consider the specific circumstances of the various operational forms, are presented in Section 4.12.2, 4.12.3, 4.12.4.

As suggested in reference [3] the following criteria should be differentiated from one another.

Service area and level of commitment criteria (for example, network density, number of stations),
Operational criteria (for example, average trip distance)
Network usage criteria (for example, average track section and station load factors).

While the criteria for level of commitment are independent of the expected transportation demand, the other two groups of criteria require informational input regarding the projected transport alternatives. The basis idea here, is to project the expected traffic stream onto the individual network alternatives (see Section 8.3).

LEVEL OF COMMITMENT CRITERIA

- Track length in kilometers (km)
- Network density $(km/km^2) = \frac{\text{length of track}}{\text{projected service area}}$

  The network density gives a measurement for the relative structural costs or commitments of the various network alternatives.
- Number of stations (HST)
- Mean distance between stations (km/HST)

  This value gives a comparison standard for the average length of track per station.
- Station density $(HST/km^2) = \frac{\text{number of stations}}{\text{projected system service area}}$

  The station density is an expression of the network commitment.
- Number of junctions on the network (Nv)

- Junction density of the network (Nv/km) = $\frac{\text{number of network junctions}}{\text{length of track}}$
- Residents in the station service area (E)
- Number of persons having business or employment in the station service area (B)
- Level of commitment:

$$\frac{\text{Residents in the station service area}}{\text{Residents in the projected system service area}} \cdot 100\%$$

$$\frac{\text{Number of persons having business or employment in the station service area}}{\text{Number of persons having business or work in the projected system service area}} \cdot 100\%$$

- Area of the station service area (km^2)
- Area covered

$$\frac{\text{Area of the station service area}}{\text{Projected system service area}} \cdot 100\%$$

- Track section potential

$$\frac{\text{Number of residents in the station service area}}{\text{Track length}} \quad (E/km)$$

$$\frac{\text{Number of persons having employment business in the station service area}}{\text{Track length}} \quad (B/km)$$

- Station potential

$$\frac{\text{Number of residents in the station service area}}{\text{Number of stations}} \quad (E/HST)$$

$$\frac{\text{Number of people having employment or business in the station service area}}{\text{Number of stations}} \quad (B/HST)$$

OPERATIONAL CRITERIA

- Mean trip length (km traveled per passenger per trip). The mean distance per trip within a network alternative is calculated from the mean value of the length of the individual passenger trips. The mean distance traveled per trip offers the first idea as to the transport situation on the network.

- Mean and maximum waiting times for passengers in the station.

NETWORK USAGE CRITERIA

- The mean station load is calculated directly as the mean value of the individual load at all stations. It is, therefore, independent of the track layout of the various network alternatives. It is determined only from the service area of each station, and the zoning (i.e., commercial, residential, etc.) within the station service area.

- The mean track section loading is calculated by the total passenger kilometers on the network divided by the network length in kilometers. It is, therefore, a measure of the economy of the individual network alternatives. If the maximum section load is given, then this criteria can be expressed in the form of a mean usage level.

- The number of persons transported per track kilometer is a measure of the success of the network layout in relation to the passenger demand. In contrast to the average track loading, this criterion is independent of the number of detours or indirect routes within the network alternative.

4.12.2 Destination Specific Discretionary Travel (demand mode)

It is desirable to have a large amount of traffic needs which can be covered within the service area borders of a specific destination discretionary travel system, since it is here that the advantages of not having to transfer are especially important. Traffic backups and/or empty spaces on cars are to a large extent avoided with such a network. The homogeneous traffic distribution which is strived for in such a system is especially suited to a high proportion of "many-to-many" transport requests.

Heavy traffic at a given station, for example, such as might occur when such a system is used as a feeder line for a conventional railroad station, should not be channeled through a single or central station. It should be divided among several junction points, in order to avoid buildups at a few transfer points, and the associated traffic backups and capacity bottle necks [31].

The stations for specific destination discretionary travel must be constructed as off-line stations, in order not to hinder the through going vehicle stream.

The requirement for specific destination travel leads to the grid network configuration, which is to be comprised of single direction loops. Various theoretical network configurations (see Figure 4-90) for destination specific discretionary travel are given in reference [31].

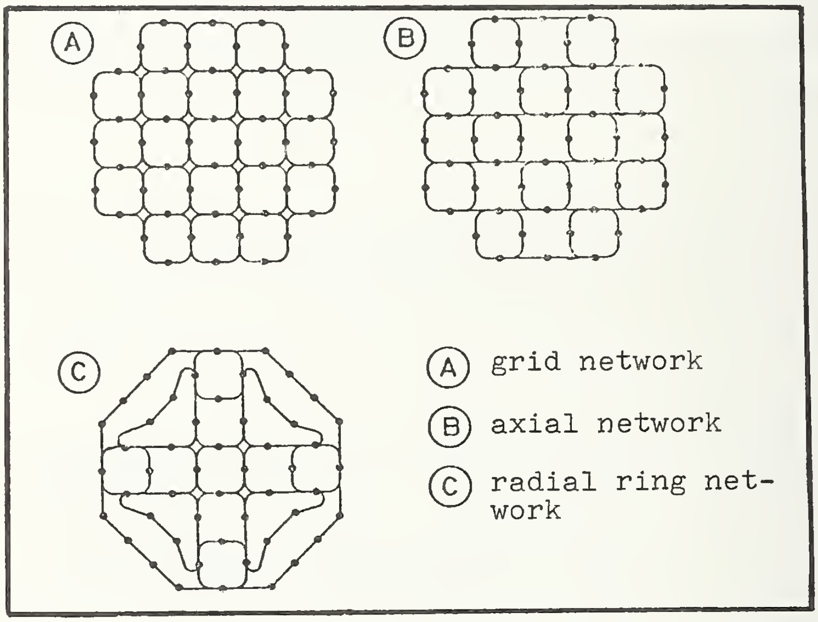


Figure 4-90. Network Configurations Source: [31]

THEORETICAL NETWORK CONFIGURATIONS

Network A is suited to a high level of commitment for local traffic, in that even distribution of trips across the network is to be expected.

Network B, on the other hand, is suited for service of traffic streams which are concentrated along certain axes, since one direction of travel is given clear preference.

The radial-ring network (network C) illustrates the concept which would be used for service of a middle-sized town. In the network arrangement, preference is given to the central area.

Networks planned for actual systems would contain elements of several of the theoretical basic network configurations (see examples).

CRITERIA FOR NETWORK EVALUATION

As a supplemental to the criteria mentioned in Section 4.12.1 for the evaluation of network alternatives, the following criteria could also be applied to networks having the destination specific discretionary travel operational form:

The unweighted indirect route factor [12] is the criterion which gives a quick and good overview as to the required minimum travel distance between all stations in the Cabinrail System, in comparison to the straight line distance between the stations. For some stations in specific cases, this unweighted indirect route factor can be adjusted for each station. Such adjustments can be of interest and give indications as to possible means of system optimization.

$$u_{i,j} = \frac{s_{i,j}}{l_{i,j}}$$

$$U = \frac{\sum^{n} u_{i,j}}{n}$$

s = track length to be traveled

l = straight line distance (as the crow flies)

i = origin station

j = destination station

n = number of traffic alternatives (stations i to stations j) (see also next page)

u = individual detour (or indirect route) segment

U = unweighted indirect route factor

The indirect factor for theoretical Cabintaxi networks is calculated according to [31] to be:

Network A U = 1.75

Network B U = 2.20

Network C U = 1.93

The network alternatives planned for Marl (see example, Figure 4-93) have indirect route factors between 1.781 (network B), and 1.84 (network C) on Table 4-12.

For comparison, the indirect route factor on normal street networks is about U = 1.2. For bus networks, the indirect route factor is somewhat higher. for example, U = 1.4 for the type of network in Berlin-Spandau. Source: [31].

Evaluation of the quality of the way in which traffic is handled within a network alternative is only possible when the actual shortest distance being traveled on the network is compared to the corresponding straight line distance between stations. For this, the mean weighted indirect route factor [31] serves as a criterion of network operation, which is obtained by weighting all indirect route factors of each origin to destination alternative with the accompanying traffic load. The weighted alternative route factor, therefore, shows the general suitability of the network alternative for the existing load situation.

$$U^* = \frac{\sum_{i}^{n} u_{i,j} \times F_{i,j}}{\sum_{i} F_{i,j}}$$

where:

$F_{i,j}$ = Load of the traffic stream (passenger trips) from i to j

$u_{i,j}$ = Indirect route factor of the trip from i to j

U^* = Mean weighted indirect route factor for the network

n = Number of origin to destination (stations i to stations j)

The weighted indirect route factor for a theoretical Cabintaxi network is calculated according to [31], to be between 1.7 (network A and B) and 1.8 (network C). The indirect route factors for the various network alternatives for the planned network at the city of Marl, are illustrated in Table 4-12.

A further criterion for planning are the options for circumventing a track section on which a malfunction exists. The smaller the grid sections upon which a network is built, the shorter would be the alternative routes for a cabin in case of track section malfunction. The grid network shown in Figure 4-91, with at least 9 grid squares and 24 switches, offers an option for easily circumventing any track section which may have a malfunction. However, a network with radial-ring structure, especially with a long section in the outer ring, does not offer good detour possibilities since there are few demerges.

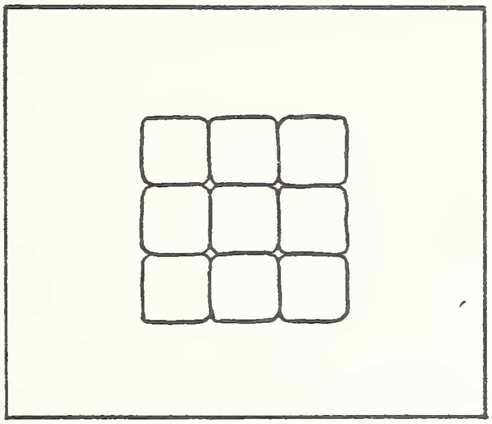


Figure 4-91. Grid Network Structure with 9 Grid Sections

The ratio of traffic load for the two traffic levels of the Cabintaxi system (suspended and supported) is expressed as the degree of symmetry for that network alternative. For daytime traffic, at least, the most even distribution of load between the two levels, that is a degree of symmetry close to 1.0, should be strived for.

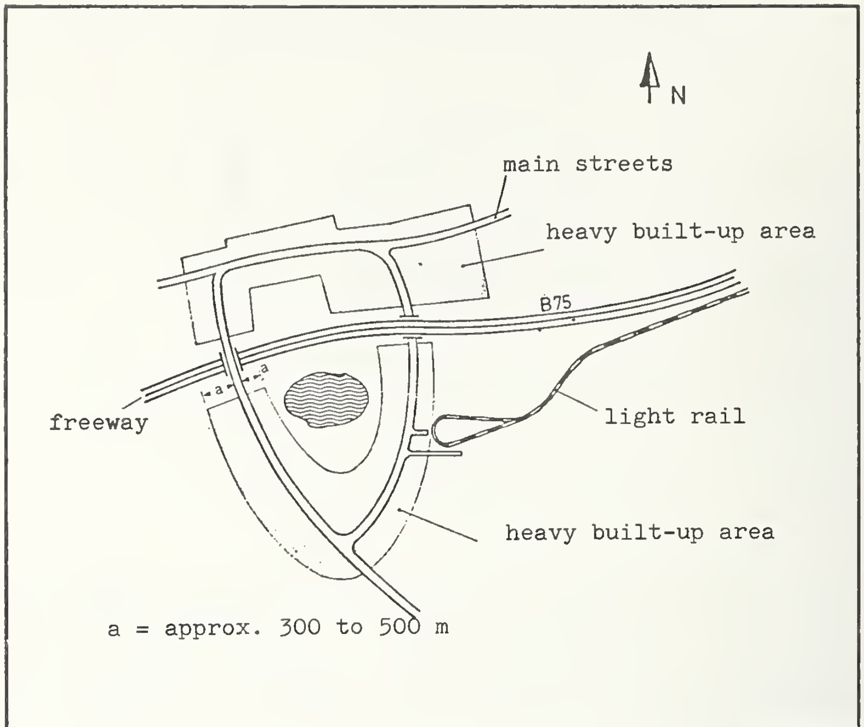
EXAMPLES FOR NETWORK PLANS

For Cabintaxis used in specific destination discretionary travel there are already a number of planned networks for which more or less exhaustive studies have been made, for example, for Freigurg [8], Hagen [9], Hamburg-Allermohe [34], Hamburg-Farmsen [35], Munich-Perlach [36], Berlin-Spandau [31], Bremen-Huchting [16], and the city of Marl [26]. The following sections will discuss the studies carried out for the development of networks in the latter two cities [16, 26].

BREMEN-HUCHTING

The network designed for discretionary destination specific travel using 3-seat cabins for Bremen-Huchting is illustrated in Figure 4-92.

The connecting of the Bremen-Huchting suburb to the downtown Bremen central area is accomplished at the present time by the Bremen Public Transport System, operating according to a schedule. The task of future public transport in Huchting is to give the people there good connection to the existing city transport, and to provide a reasonable alternative to individual transportation for overland travel.



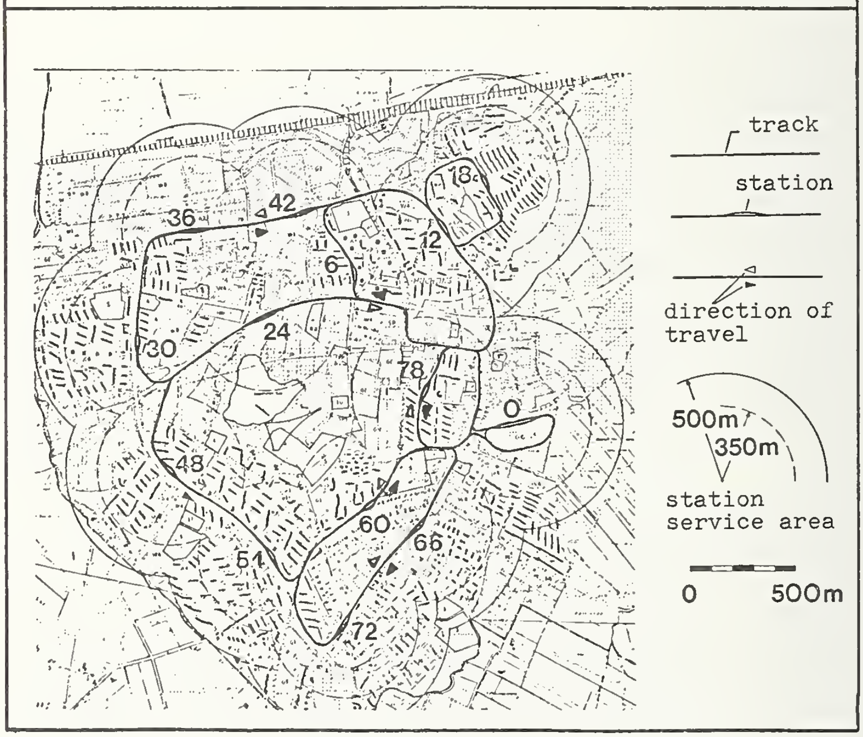


Figure 4-92. Cabintaxi Bremen-Huchting

The system layout of the Cabinrail is dictated by the ring-like structure of the buildings and streets.

CITY OF MARL

As described in Section 4.12.1, a feasibility study [26] carried out for the city of Marl took into consideration the projected development of system structures (stations, track, etc.), motorization, and mobility, as well as planning for the total network. These considerations lead to an exhaustive study of various network alternatives.

Starting from the optimal network which would supply full coverage of all transportation needs, it was found that a network 85 percent as large as the ideal network could meet 98 percent of the demand in the area. Three variations of the theoretical network configurations were proposed for the Marl city area (Figure 4-93). These network variations were subject to the evaluation as described in Section 4.12.1. The evaluation criteria used for the first evaluation stage, along with the appropriate parameters, are shown in Table 4-12.

Due to the results for the network length and the indirect route factor, further network forms which are not shown here, based on Network A, were developed and subjected to further stages of evaluation(Section 8.3). This led to network variant H 2, which is shown in Figure 4-94.

4.12.3 Scheduled Line Operation

Network planning for line operation is carried out according to the conventional public transport fundamental principles, such as, for example, coverage for the main traffic stream, minimizing of the necessity for transfer, etc. These lines can be realized in the form of long ring sections (see Figure 4-95). Transfers could be made, in general, at all stations along the ring. Stations could be arranged as on-line stations in the case of exclusive line operation, or where light travel is expected. The effects of network malfunctions on a line operating network which has few detour or route alternatives, can be very severe. Therefore, heavy bunching on the lines should be avoided as much as possible.

For evaluation of line traffic networks, additional criteria aside from those mentioned in Section 4.12.1 are needed, such as the number of people making transfers between Cabinlift lines and the time which they are required

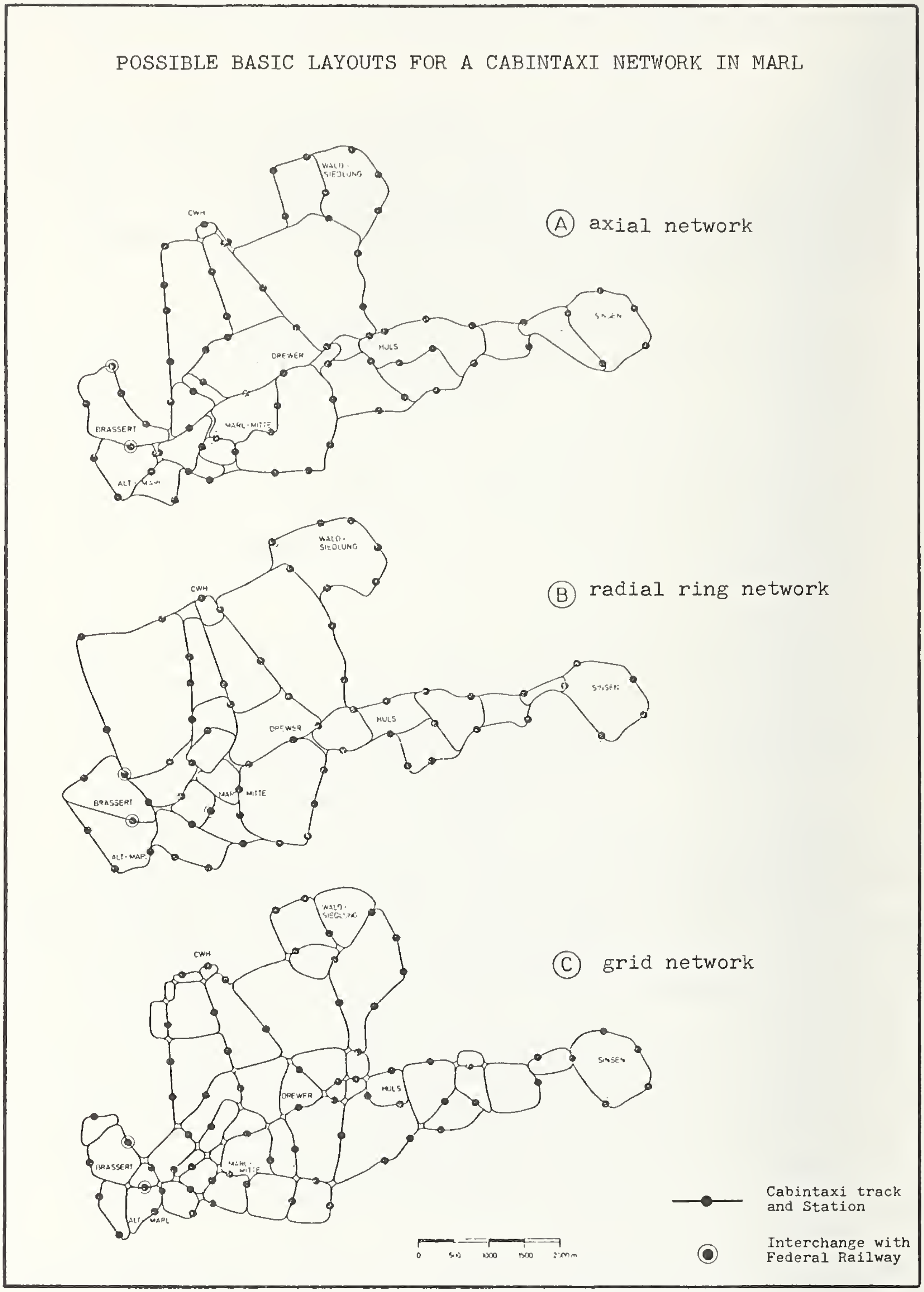


Figure 4-93. Basic Network Patterns for Marl

Table 4-12

CHARACTERISTIC MAGNITUDE AND EVALUATION CRITERIA FOR NETWORK VARIATIONS OF A CABINTAXI OPERATION IN THE CITY OF MARL

Source: [37, 38]

		A	B	C	H2
	Net land usage (hectare)	1,080	1,200	1,080	1,000
	Stations	72	67	70	60
	Track length (km)	53,420	53,570	65,430	51,450
	Station density (station/km^2·land used)	6.7	5.58	6.5	6.0
	Track section density (km·track/km^2·land used)	4.95	4.46	6.06	5.14
	Mean interval between stations (m)	742	800	935	858
	Unweighted indirect route factor	1,787	1,781	1,840	1,812
24 h Load	Passengers conveyed (passenger journeys)	75,437			
	Conveyance potential (pass-km)	283,923	309,011	328,766	290,949
	Mean distance traveled (km) (per trip)	3,768	4,099	4,361	3,857
	Weighted indirect route factor	1,714	1,864	1,858	1,679
	Mean station load (passengers)	1,048	1,126	1,078	1,257
	Mean track load (passengers)	5,315	5,768	5,025	5,655
	Persons transported per km track	1,412	1,408	1,153	1,466
	Degree of symmetry	1.00	1.01	1.01	1.01
Peak Hour Load	Number of people conveyed (pass journeys)	9,868			
	Conveyance capacity (pass·km)	38,304	40,847	45,352	38,872
	Mean distance traveled per trip (km)	3,884	4,140	4,598	3,939
	Weighted indirect route factor	1,676	1,791	1,879	1,647
	Mean station load (passengers)	137	147	141	164
	Mean track load	717	763	693	755
	Persons transported per km track	85	18.4	.151	.192
	Degree of symmetry	1.02	1.01	1.11	1.02

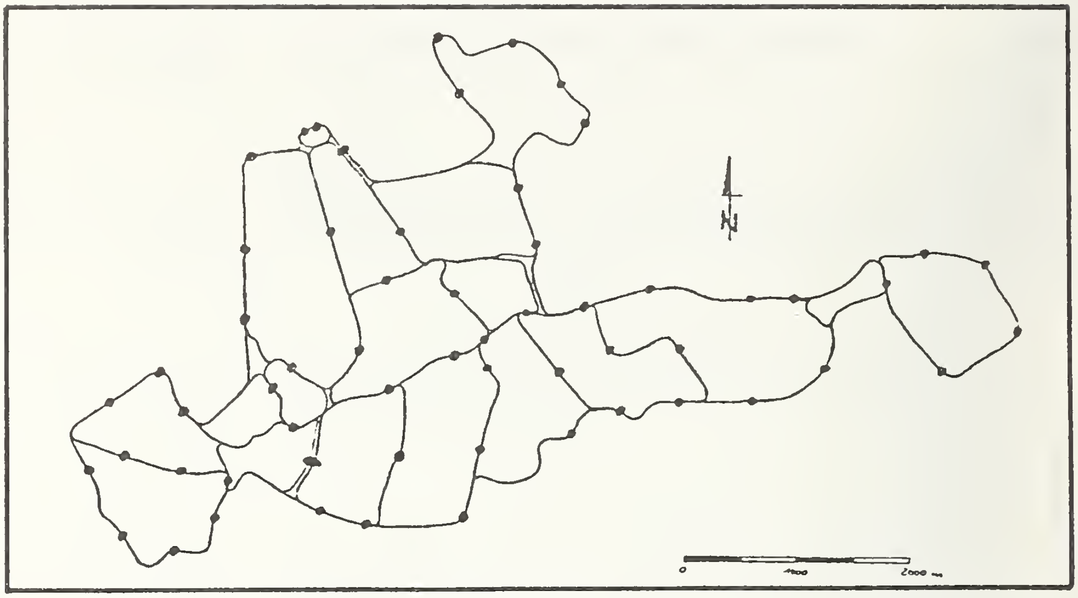


Figure 4-94. Marl Cabinrail - Network Variant H 2

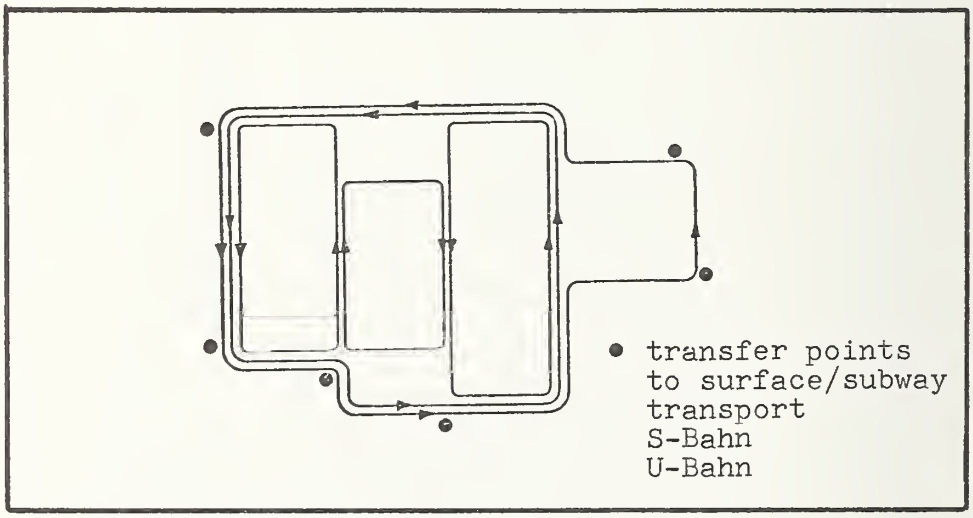


Figure 4-95. Course of the Line

to wait, as well as the number of transfers which a given passenger may make. Optimal coverage of the main traffic stream can mean an improvement in the overall attractiveness of the system.

As a final improvement stage, dynamic simulation is an option (see Section 4.13). The simulation yields results based on the initial parameters on which improved operation may be gained (for example, number of vehicles and/or station docking points).

Planning for line operation in one of the northern sections in the city of Munich [39] can serve as an example of a Cabinrail network in short line operation. This network is illustrated in Figure 4-96; the network structure utilizes the double track guideway.

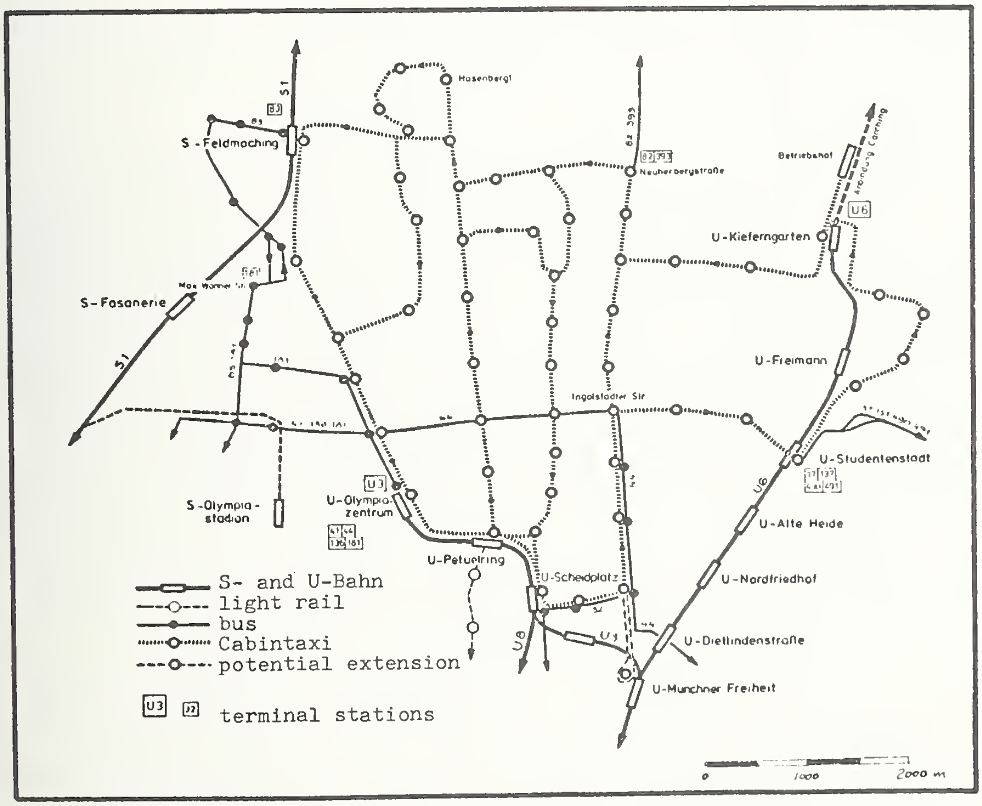


Figure 4-96. Network Structure in Section of Munich

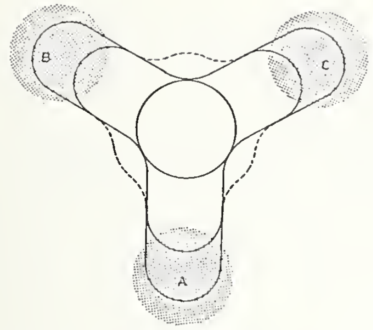
In this example, the KK12 Cabinrail vehicle is integrated into the existing urban transport network, and has feeder and distribution functions with respect to the existing rail systems (underground conventional rail).

Several ring or loop lines take over the service of the north-south main traffic stream, which carried passengers from the residential areas in the north to the conventional rail stations in the south. These ring lines mesh into one another "like gear wheels", and in sc doing increase the coverage along the track section.

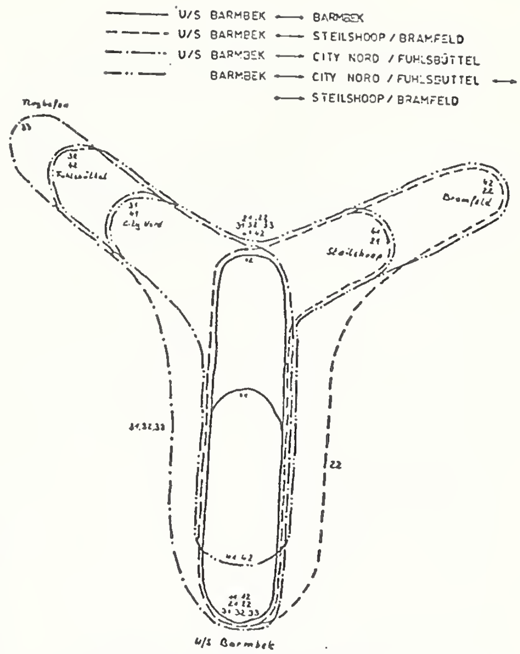
An outer ring is designed to assume the tangential traffic in the east-west direction; in this way, crossing with the normally associated elements is avoided. Along track sections leading to the subway stations, this ring line increases the transport capacity of the feeder oriented service. The bus lines which radiate into the area under investigation from outside are also connected with the Cabinrail.

In the feasibility study, for a reference facility to provide public transport in Hamburg [4], the course configuration for a Cabintaxi network for twelve different areas of the city was proposed. Detailed network alternatives were then worked out for three selected areas (from the original 12), with consideration being given to the special features of the city structure and architecture. The networks are, to a large extent, similar to the existing bus line networks. On the basis of cost comparisons, especially considering the traffic structure which has a relatively high amount of traffic with destination within the service area and traffic a sufficient load in off-peak hours, a network was selected and investigated further (Figure 4-97). A table listing the various parameters relative to this network alternative is shown in Table 4-13.

Basic thinking with regard to this network design, was to arrange the double track groups so that two short pathways would exist between the three heaviest transport usage points A, B, C (Figure 4-97). The doubled layout of the most important point-to-point connections helps promote the capacity performance of the system, and reduces the susceptibility of the planned system to malfunction [17]. For the central portions of the network, later introduction of



principle of the track layout



line layout

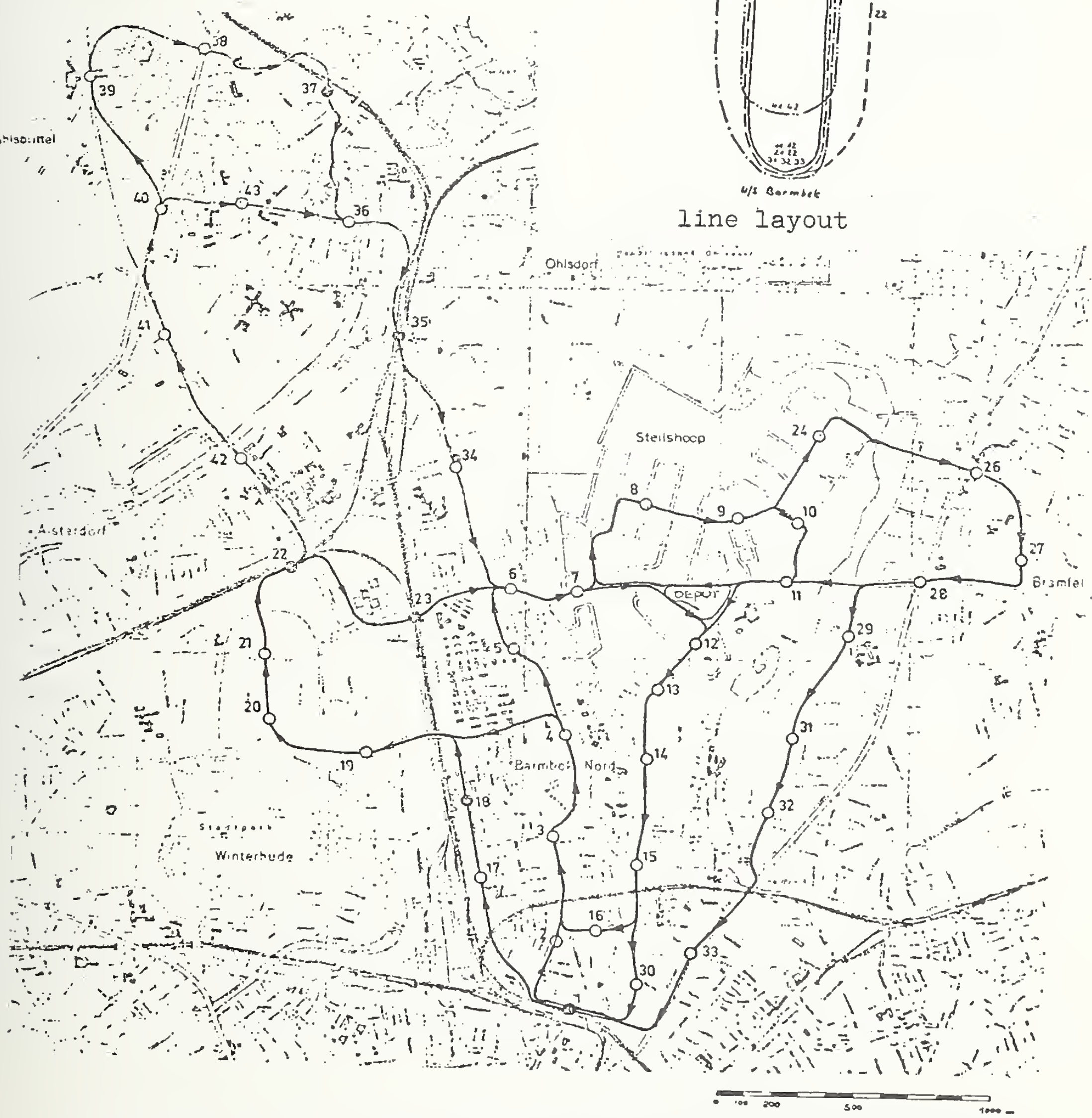


Figure 4-97. Network Formation and Line Structure for Hamburg

Table 4-13

NETWORK DATA FOR HAMBURG

	FEATURES	DIM.	VALUES
	Structural data (from 0 2)		
1	Population	(E)	101,500
2	Number engaged in business or work	(B)	51,300
3	Land area of the proposed service coverage	(gkm)	12.4
	C rail network		
4	Track length	(km)	25.5
5	Network density	(km/gkm)	2.1
6	Number of stations	(Hst)	35
7	Mean distance between stations	(km/Hst)	0.73
8	Station density	(Hst/gkm)	2.8
9	Number of network junctions	(Nv)	12
10	Network junction density	(Nv/km)	0.47
11	Number of residents in the station service area	(E)	97,200
12	Number of people working in the station service area	(B)	48,740
13	Level of commitment with respect to residents	(%)	96
14	Level of commitment with respect to people working	(%)	95 (estimated)
15	Land area in the station service area	(gkm)	10.5
16	Land area having coverage	(%)	85
17	Potential use of each track section by residents	(E/km)	3,810
18	Potential use of each track section by workers	(B/km)	1,910
19	Potential use of the stations by residents	(E/Hst)	2,780
20	Potential use of the stations by workers	(B/Hst)	1,390

1) The parameters #11 and 12 are based on the number of residents or workers in the station service area.

network augmentation is optional (broken line), which would avoid the stoppage of traffic in case of a malfunction.

In this system, aside from line service with discretionary stops which is the type of service to be utilized, or a schedule-controlled line operation, destination specific discretionary transport is also possible. In Figure 4-97 the line layout for the selected operational form is illustrated.

Combined Scheduled and Discretionary Mode

This operational form is planned especially for the Cabinlift in facility dedicated systems. The network planning, therefore, must be oriented for the most part to connect the points which are to receive service (i.e., buildings). One important question here is the integratability of stations into existing buildings.

The stations can be designed as on-line or off-line according to the amount of projected usage. For determination of the most effective network configuration, dynamic simulation may be useful, as well as the steps mentioned in Section 4.12.2. As an example of network planning, the proposed network for the St. Jurgenstrasse Central Hospital facility in Bremen is shown (Figure 4-98).

4.13 DYNAMIC SIMULATION

Computer simulation is an important side in the development process, and also an instrument for planning. Initially, computers were used chiefly by the manufacturers in simulation for the development of the switching concept in relation to the interval measuring system. Currently, dynamic simulation is used for the development of total system operational procedures, as well as for individual system components such as stations. In addition, computer simulation is also utilized to optimize the guideway geometry and estimating system costs.

4.13.1 Simulation of Operation Procedure

4.13.1.1 Methodology and Purpose

Dynamic simulation offers the option to present the operational procedure on the traffic network realistically, so that they may be checked and optimized.

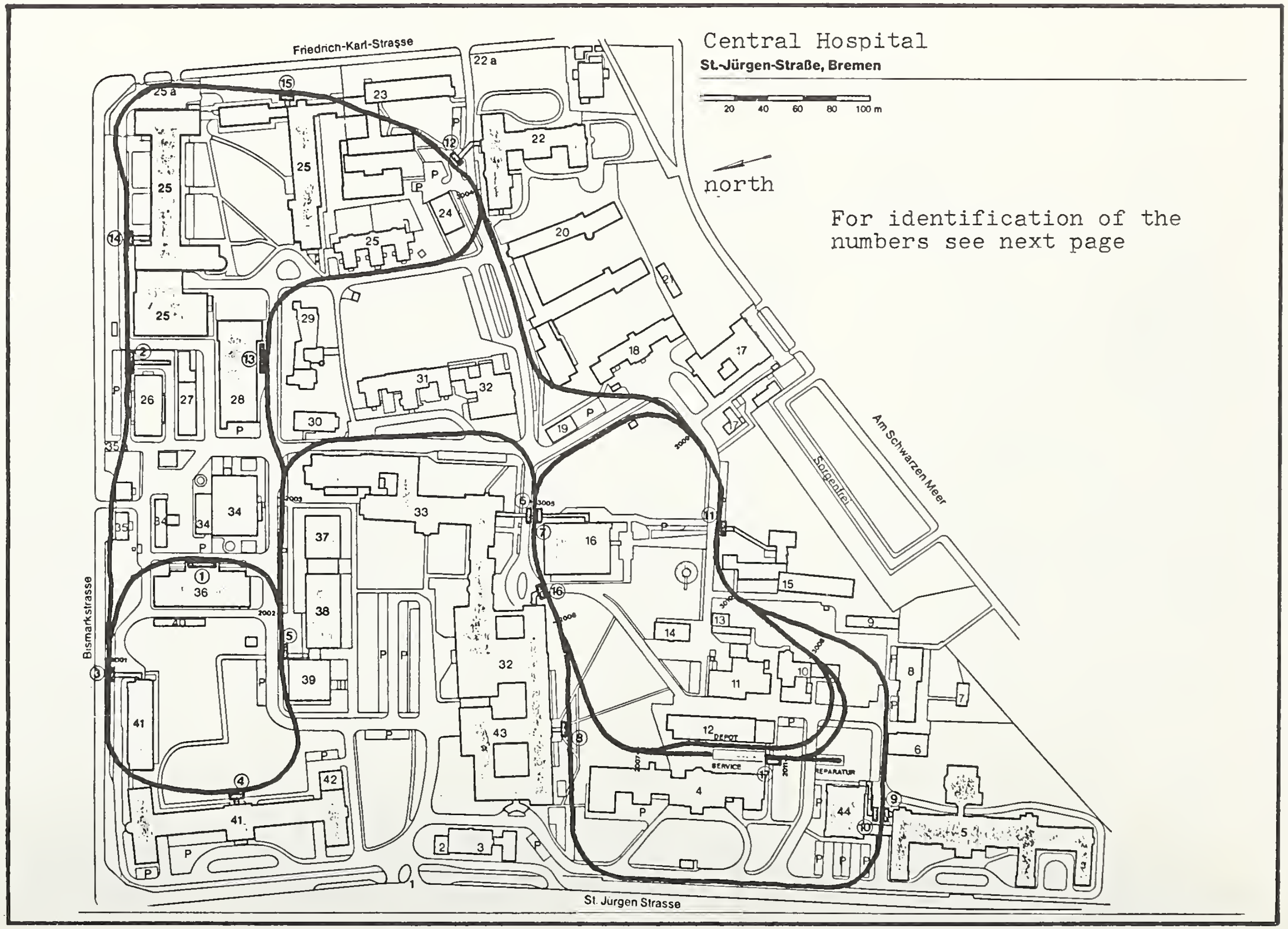


Figure 4-98. Cabinlift Network, Bremen

It will be an important instrument in the first demonstration facility project, and can assist in the development of the operational software.

In the mathematical analysis (static simulation), continual passenger and vehicle flow over the investigated time periods (peak-use hours) are calculated; dynamic simulation is used to follow individual vehicles both on the network and in the stations during the entire simulated operation. The interaction of vehicles with passengers, as well as the various times taken by passengers to board and deboard, are also considered.

Since the simulation process reflects all movement in the planned transport process and makes this visible in a color display (see Figure 4-99), effects of insufficient vehicle availability or of system malfunctions can be studied in detail, and appropriate strategies for the solution of such problems can be developed in dialogue with the computer. In networks with a large amount of loops, for example, other routes could be used in case of system malfunctions. For traffic in the double guideway areas, passengers might be redirected onto the operating travel levels. In Cabinlift systems, a change in scheduling appropriate to the time needed to repair malfunction might be possible.

During simulation, the network or part of the network affected is denoted by wide colored stripes on the system layout map. Empty and occupied vehicles are marked by various colored points.

Figure 4-99. Color Display

The dynamic simulation also considers the algorithms for vehicle headway measuring, and the imaging of vehicles in merges.

Various problems were to be solved by simulation during the Cabintaxi development process, given the basic vehicle sizes and operational procedures. Up until the end of 1976, simulation had been carried out on the 3-seat small cabin. Since the beginning of 1977, the simulation activity has continued for the larger vehicles (12-24 passengers). The main task of simulation for the larger cabins consists of the optimization of design layout, the development of operational strategies, determination of the number of vehicles, and the waiting time attained by variation of various line layouts and station configurations.

For the Cabinlift, such investigations deal especially with the effect of the stop time of individual vehicles, loading and unloading after schedule, on the stop time and travel time of discretionary traffic in on-line and off-line operation. The number of vehicles needed and the overall waiting time was determined by schedule optimization on a suitable network configuration. These two parameters were then further optimized with respect to each other. Such investigations are presently being used in the detailed planning of the Bremen Cabinlift facility.

Simulations for operation of 3- and 12-seat cabins have been carried out. The results are presented below.

4.13.1.2 Simulation of Station Operation (KK3)

In reference [40], an off-line station, decoupled from the network, is shown utilizing the KK3 cabin in destination specific discretionary traffic operation. The operational mode influences the way passengers are handled. This example also considers to what extent various parameters can be used to control the operational procedure of the station (see Figure 4-100).

The parameters used are:

- Waiting time of the passengers
- SP = required buffer capacity: that is, the minimum number of available cabins required in the station. If the number of cabins available falls below the minimum, then cabins are ordered from Q.
- n_a = number of deboarding points

- n_e ($\leq n_a$) = number of boarding points
- FZL = vehicle limit, which is the vehicle storage capacity of the station.

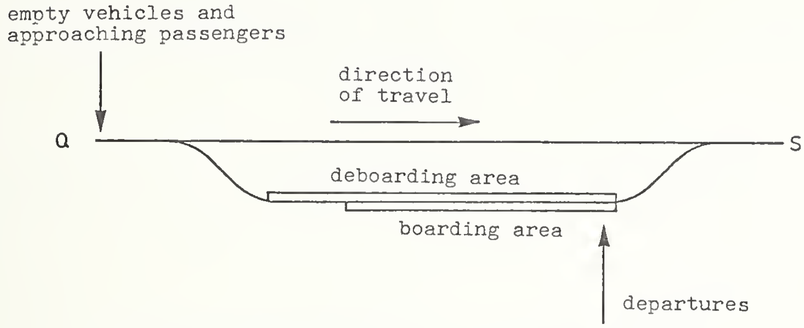


Figure 4-100. Diagram of a Single Station

The time which the passengers spend in the station is segmented during the times spent boarding and deboarding (according to a Poisson distribution). The introduction of empty and occupied cabins over the simulation time interval was carried out using a random number generator (in this case the simulation interval was 1 hour with isotropic distribution).

In Figure 4-101, the waiting time given for passengers at a 4-berth station ($n_a = n_E = 4$) is given for three different buffer capacities.

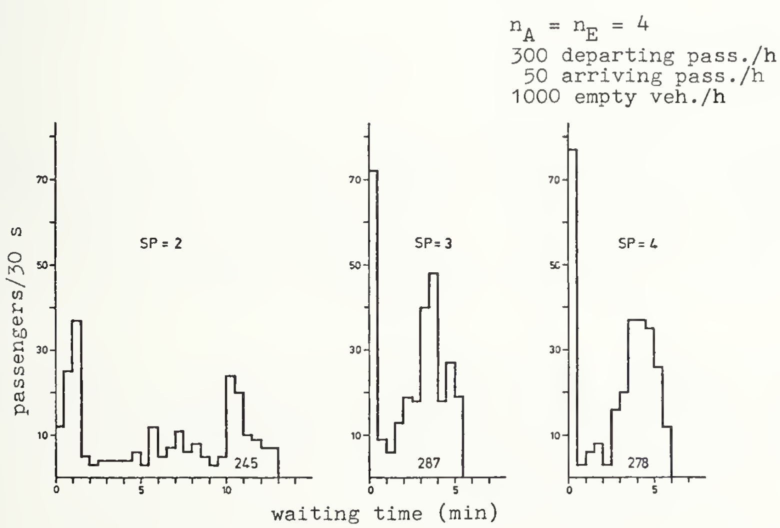


Figure 4-101. Variations of Buffer Capacity

In this simulation exercise, the waiting time naturally decreases with better empty cabin supply at the station (that is, as the buffer size increases). At SP = 4, however, the station passenger capacity decreased again; since to accommodate arriving cabins which are occupied, empty cabins are moved out without taking passengers, causing an increase of vehicle movements in the stations.

The same thing applied to the waiting time when varying the number of available empty cabins/h (Figure 4-102).

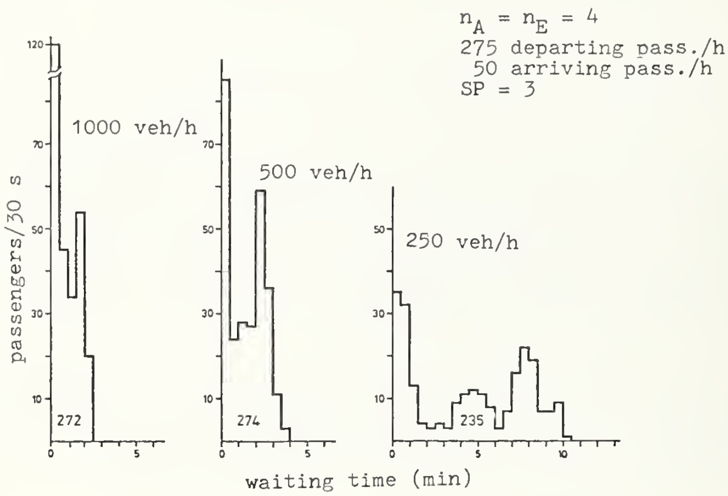


Figure 4-102. Variations of the Available Empty Cabins

In these two examples, the comparison between the cabins available to the station per hour and in the buffer resulted in a fairly slow response time to a passenger's call for a cabin. Therefore, three further options were studied (see Figure 4-103):

1. The cabins would be removed from the cabin reserve supply immediately upon completion of the boarding procedure.
2. The cabin will be removed from the station reserve at the beginning of the boarding procedure.
3. The number of passengers waiting would be sensed and applied to the control of the empty cabin supply.

arriving passengers equals
departing passengers

500 empty veh/h

station: passengers/FZL, n_A, n_E, SP

(a) 300/6, 4, 4, 1

(b)-(e) x /6, 4, 4, 3

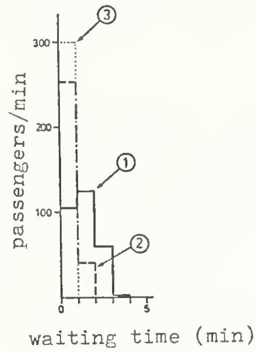


Figure 4-103. Waiting Time for Cabins for Options 1, 2, and 3

The problem of backups on the approach track to the station was raised. This can happen especially in the case of a "too good" empty cabin supply (case 3), if none of the approaching occupied cabins are made to bypass the station. The possibility and effects of a backup, which would extend to the main track section, should be studied using network level simulation.

Investigations of the waiting time with large numbers of passengers shows that the number of passengers which can be processed under 1 minute in case 1 is a maximum of 300, while using model 2 and 3 about 500 passengers could be processed. However, case 3, because of its increasing refusals to admit cabins (in order to avoid a backup), requires a larger number of cabins at passenger densitities of higher than 400 passengers/hour.

In network level simulations carried out to date, using station control model 2 and having a good empty cabin disposition through suitable arrangement of the station, the waiting time for passengers was held to under three minutes. The waiting time for 80 percent to 90 percent of the passengers was less than 1 minute.

4.13.1.3 Network Simulation (KK3)

In this section, network simulation carried out for a feasibility study on the KK3 cabin in destination specific discretionary travel for the city of Marl [26] will be discussed.

Aside from the step-wise improvement of the network configuration and operational strategy, the operational software algorithm was also developed using this network simulation.

The dynamic network simulation represents the network, stations and switches, and includes the control algorithm for the distribution of empty cabins, as well as for detours. The simulation of off-line stations (see preceding section) was done here in connection with the operation of the total network. As mentioned, the acceptance of vehicles into the station was controlled by the buffer (SP) and the vehicle limit (FLZ). Isotropic distribution during peak hours was established as a basis for the on-going statistical simulation prognostications for the number of passengers using the station. The average level of occupancy was taken as 1.35 passengers per vehicle. The location of the vehicle storage depots was based upon the structural rail particulars of the city (i.e., where such buildings could be constructed with acceptable cost and effect on existing structures), as well as the minimizing of the number of kilometers traveled by empty vehicles. These considerations lead to the assumption that there would be three depots, having a capacity of 200 cabins each for each track level (top mounted and suspended).

An important task for the dynamic simulation of the Cabintaxi KK3 is to work out the procedure with respect to distribution of empty cabins. An empty cabin disposition is considered optimal when the required number of vehicles, waiting time for passengers in the station, as well as the average number of kilometers traveled by empty vehicles, are concurrently held to a minimum.

Before the actual peak hour simulation run begins, i.e. the boarding process starts in the stations, the vehicles must be released from the depots at the proper times and sent to the stations. This disposition of empty cabins is accomplished "in advance." The advance time is equal to the time which it takes for the vehicles to travel from the depot to the most distant station.

On the Marl network this is an advance release time of about 15 minutes. From the beginning of the "main run," essentially all of the station reserve positions are filled.

The optimal parameters for the network control were determined a step at a time by variations of the number of vehicles released from the various depots, variation of the boarding positions and the reserve positions in the stations, and consideration for the requirements for distributing the waiting time fairly among the passengers. The requirements were that 80 percent of the passengers would have to wait less than 1 minute, and less than 2 percent of the passengers would have to wait over three minutes.

After determination of the optimal network control parameters, several runs were made during which the time distribution for the time points at which the passengers would arrive at a station was changed. When the parameters finally were appropriate to the mentioned requirements (the waiting time for the total number of passengers fall within the required limits) these parameters were selected.

RESULTS

Dynamic simulation of the Cabintaxi operation for the afternoon peak hours supplied the following data:

- The number of vehicles required for both guideway levels,
- The waiting time at the individual stations,
- The capacity of both guideway levels,
- The number of docking points in the station,
- The required capacity of the individual vehicle storage depots.

For the network configuration H2 with 62 stations, resulting from the previously mentioned iterative improvement process (Section 4.12.2), the following values were obtained:

- The waiting time of approx. 2% of the passengers was more than three minutes.
- On level 1, 767 vehicles were required; and on level 2, 793 vehicles were required.

The size of the stations was determined by the required number of boarding and deboarding points (n_E, n_A), as well as the vehicle reserve (SP). Accordingly, four stations on two levels must have six boarding points apiece. All other station should be four boarding point stations. As the station reserve, 124 (2x62) vehicles should be kept in the stations.

Previous thinking with regard to the positioning of the vehicle storage depots was confirmed through dynamic simulation. The size of the depots had to be revised. The optimal supply of vehicles to the stations required taking into consideration the situation on the network as a whole, resulting in various size depots, the capacity of which was asymmetrical on the two guideway levels. Aside from the vehicles positioned in the stations, approximately an additional 650 vehicles on level 1, and approximately an additional 80 vehicles on level 2 have to be accommodated in the depots.

The overall conveyance capacity on level 1 was:

- 22,594 vehicle kilometers with 36.7% empty vehicle travel and on level 2
- 22,906 vehicle kilometers with 37.5% empty vehicle travel

The proportion of empty vehicle kilometers was considered satisfactory at about 37 percent.

4.13.1.4 Network Simulation (KK12)

In the simulation carried out for the feasibility study for Hamburg (KK12 vehicles) [12], guideway optimization with respect to a number of parameters was investigated: the influence of additional track sections on the required number of cabins, the distances which must then be traveled and the waiting time. Aside from that, the effects on the waiting time, travel time, and required number of cabins was determined by varying in the type of stations, (on-line, double on-line, off-line, and station boarding points). Furthermore, lines which traveled over the same guideway could vary from another with respect to the points at which they actually stopped (for a discussion of line configuration see Section 4.12.3).

After optimization of the guideways, the simulation for the KK12 operation was carried out at an IBM-370 computer facility. As initial data for these

studies, station matrix was used for various groups of hours during the day having the appropriate traffic density. In addition, an overall passenger trend factor, the configuration of the lines, the previously estimated number of vehicles, and the number of vehicles per time unit on the lines were used. The program considers the passenger demand as a stochastic process to represent a picture of the transport requirements during the given times. All parameters and values leading to cost and usage considerations are contained in the output data. In addition, a protocol for evaluating the various results in detail was established.

As an example for the development of the operational strategy, the control of the headway between vehicles is described. In the first simulation runs, vehicles after leaving the station (in certain intervals) were released from control. They arranged themselves in a relatively short time into packs on every line, which naturally had a strong negative influence on the operation. It became apparent that each line must have a means of sensing and controlling the vehicle time interval (time interval control), in order to be able to correct for any "packs" which may appear to be building along a given route alternate. Several "soft" and "rigid" mechanisms were studied, until finally it was shown that the optimal solution would be not to release any of the line vehicles until the time necessary for their travel to the appropriate station had come (that is, no vehicles would be released early), and the following vehicles would then have their allowed time from storage depot to station redetermined. The proper value for the vehicle time interval, then, would continue to be recalculated as the time that each vehicle would need to travel over the whole network, divided by the number of vehicles on line. The result was a stable, even distribution of vehicles over the entire line, with the resulting positive effect on the waiting time of the passengers.

4.14 OPERATION UNDER ADVERSE WEATHER CONDITIONS

Experience as to the behavior of the Cabintaxi/Cabinlift system under adverse weather conditions has been gained during test operations at the Hagen test track (EPA), and through the operation of the Cabinlift system in Ziegenhain.

Both systems are, in general, presently suited for operation in moderate climates with outside temperatures between -25°C and +35°C. The electronics and electrical systems can operate without danger when warmed to +60°C; at low temperatures, the electronics units themselves are heated to insure proper function. Heating and ventilation for the system must be determined for other climatical zones; the installation of air-conditioning may be required. This however, does involve additional costs.

For winter operation on the "top-mounted" level at the EPA, an arrangement similar to a snow plow has been used on one cabin (Figure 4-104). This plow arrangement does not run along the guideway surface because of the possible effects of impacting against the guideway itself at the guideway connections.

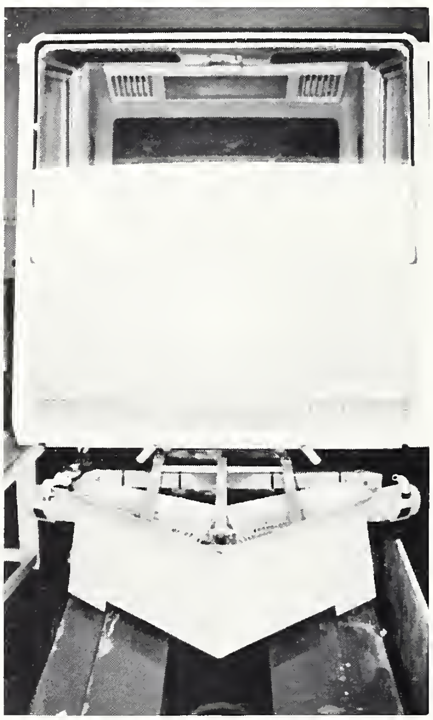


Figure 4-104. Snow Removal Attachment

The guideway outer panels or skirts prevent rain and snow from reaching the bogie and power rail area of the top-mounted level (Figure 4-105).

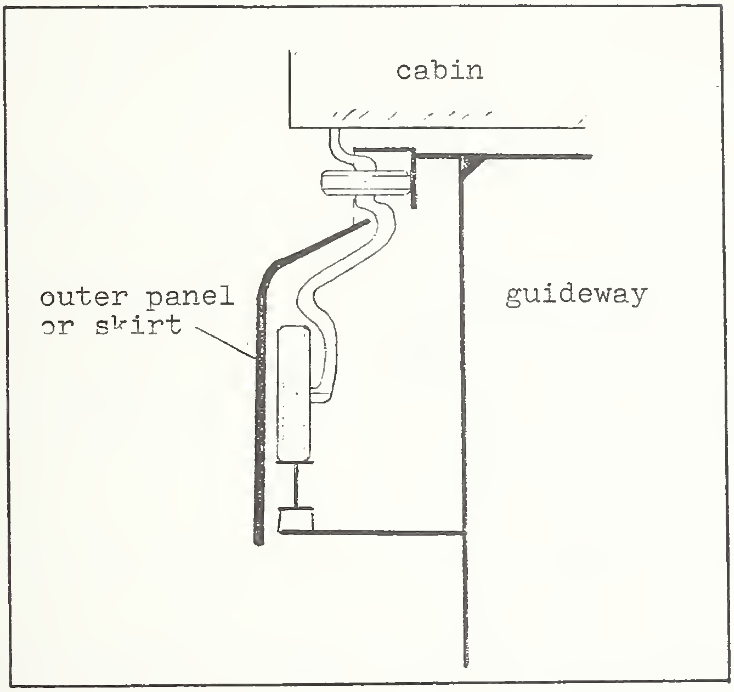


Figure 4-105. Outer Paneling or Skirting and Bogie on the Top Mounted Rail

The suspended rail is well protected against the direct influences of inclement weather, as well as water, which would reach the upper level. In low temperatures, however, the rails may from time to time experience ice build-up on the lower level, primarily through condensation from the air on cold components.

No problem with propulsion or safety are foreseen with the LIM and LIB systems which are not dependent on wheel to rail friction for acceleration of deceleration.

The danger does exist, however, that the tolerances between the propulsion and power rail elements of the vehicle and the guideway respectively could be exceeded by heavy ice buildup. The use of rock salt to prevent ice-build-up

was not pursued because of the danger of corrosion. A roller mounted at an angle ahead of the first carrier wheel, or a scraper have been seen as possible ways of solving this problem (Figure 4-106). These arrangements would destroy the ice layer and push it to one side. Up until the present time, ice and snow build up on the guideway at the EPA has been prevented to a large extent by continual operation during the night time hours as well as the day time. The snow plow was used only in an experimental sense.

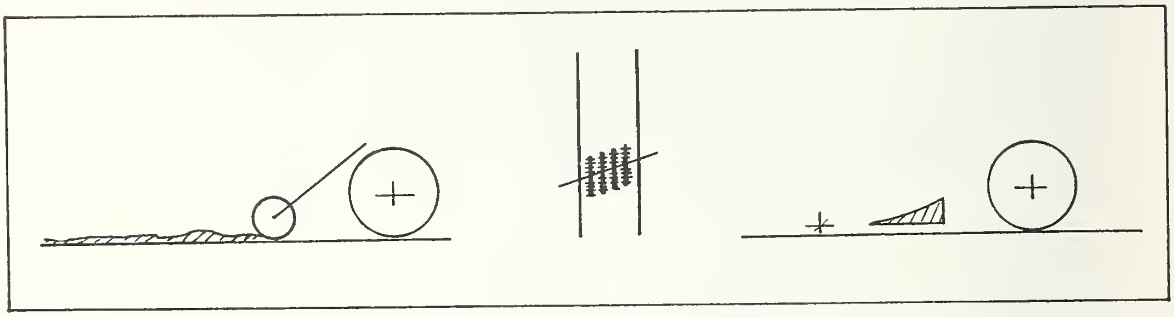


Figure 4-106. Arrangements for Use Against the Buildup of Ice Along the Guideway Rails

Operation at the EPA, as well as at the Cabinlift facility at Ziegenhain, has been carried out regardless of the weather. However, these systems are located in the climatically moderate middle European zone. There have been no malfunctions or influence upon operation accountable to weather at the Ziegenhain Cabinlift at the present time. This may be due in some part to the protection afforded by the suspended cabin design of this system. At the EPA, various measures were introduced for winter operation on the top mounted level; equipment to be used against the build up of ice on the carrier rails is presently in preparation. The installation of this equipment will allow operation during the most extreme weather conditions encountered in the moderate German climate without problems. Experience as to the behavior of the system under extreme weather stress conditions is not yet available.

5. SYSTEM OPERATIONAL DEPLOYABILITY ASSESSMENT

Visits were made by U.S. Government personnel to West Germany during July and October of 1976 for the purpose of reviewing the development, deployment, and operational status of the Cabintaxi and Cabinlift systems. At the time of these visits, the evolving Cabintaxi/Cabinlift technology had not been deployed in the public domain, although experience had been gained since 1973 on a large test track in Hagen, and a Cabinlift system had been installed on private property at a hospital in Ziegenhain. The Cabinlift system at Ziegenhain consists of a single large vehicle which shuttles on a single length of guideway between two hospital buildings, and utilizes selected portions of the overall system technology modified to fit the specific application. (See Appendix A for discussion of the Ziegenhain Cabinlift system.) Other components or features of the Cabintaxi/Cabinlift systems were in various stages of conception, design and development, or in operational testing status at the test track in Hagen.

This section of the report relies on Chapter 4. for a detailed technical description of the various components and subsystems, and addresses some of the major considerations relevant to deployment of the Cabintaxi system in a network configuration, i.e., any system more complex than a simple loop or single vehicle shuttle. The current status of elements or items relevant to deployment are discussed. Human factors considerations are addressed in Chapter 6.

5.1 THE BREMEN CABINLIFT SYSTEM

The planning activities and state of deployability of the Cabintaxi/Cabinlift technology for the Bremen Hospital system were of particular interest during this assessment, since Bremen represents planning for the first multi-vehicle, network-configured deployment of the system. Issues relative to Bremen permeated many discussions with various people in differing technical and geographic areas over the course of the October, 1976 visit. The subject is summarized here and mentioned in subsequent text.

The Center Hospital at Bremen has significant area transportation problems stemming from its layout which has evolved through several decades. The system designed for Bremen is primarily intended to move patients, hospital personnel, and hospital supplies (bedding, good, medicine, laboratory specimens, etc.).

During times of non-critical hospital usage, visitors may also be permitted to use the system. The hospital employs 2800 people, has 25 main buildings, and sits on a 400 x 500 m area.

The Cabinlift system currently proposed for Bremen will have 2.8 km of overhead guideway with 16 vehicles and 17 stops at clinics and at the service building. The system design is complicated by the necessity to move "clean" and "dirty" (used bedding, etc.) cargo in different dedicated vehicles. Cost estimation and construction have been influenced by the fact that records of the location of underground and in-the-wall wiring, pipelines, etc., are not available.

On-site observations and a study of current hospital procedures formed the foundation for determining vehicle demand at the various stops, inter-stop transit time requirements, and loading and unloading times for various cargoes. Accompanying changes were proposed to the existing system of supplying meals at the hospital to make it more compatible with automated operation, and to increase overall efficiency.

Several guideway network configurations have been explored for the Bremen Hospital system. The simulation effort necessary to make the initial selection of the Bremen network was done by DEMAG. The final network design will be subjected to MBB's more detailed simulation analysis which utilizes the specific design characteristics of discrete Cabintaxi system components, such as the longitudinal control system and merges. The DEMAG simulation effort sought to minimize the number of cabins (vehicles), meet the required transport time, and minimize empty vehicle miles. Fifteen network configurations were considered for Bremen. Three operating strategies were examined for each of two final network configurations culminating in the currently proposed network of two large loops which are cross-connected, and each of which contains a smaller loop (see 4.12.3). The vehicles move in the loops of the network in one direction only (counterclockwise). The layout mainly follows the public streets without disturbing existing trees. The average height of the track pylons is 11 m. The bottom of the vehicles will be at least 4.8 m above ground throughout the entire system. Maximum upgrade is about 1.3%, and maximum downgrade is about 2.4%. Construction is planned to take place in three phases to accommodate individual clinic areas.

The vehicle planned for Bremen is not identical to that used in the Cabinlift system at Ziegenhain. It is larger and expected to weigh approximately 4.5 metric tons (as opposed to 3.2 metric tons for the Ziegenhain vehicle), necessitating some changes in the structural design of the guideway for lateral stability and strength. Vehicle dynamics (acceleration and deceleration) may be changed from 0.35 m/sec^2 at Ziegenhain to a value as high as 0.6 m/sec^2 at Bremen. The "clean" and "dirty" vehicles will differ in interior equipment. There will be approximately sixteen vehicles, two of which will be "dirty" vehicles.

The stations will consist of "stops" usually comprised of a platform 8.3 m x 3.6 m and 2.5 m wide connecting corridors of differing lengths. The stops will be built into the buildings.

The system is currently anticipated to operate daily for 16 hours, from 6 a.m. to 10 p.m. A simple central control facility is envisioned with the principle functions of scheduling, maintenance and control, destination-request processing, information display at stops and at central, and readying of vehicles from the maintenance depot. Due to the short distances between stops and the generally on-line stations, the central control philosophy may ultimately require synchronized movement of vehicles. The currently adopted operating strategy, however, relies on establishing priorities for classes of cargo movement and moving vehicles from stop to stop based on requests for priority service. Unrequested vehicles will remain at their last stop until required, or until another vehicle needs access to that stop. The detailed planning for Bremen began in March 1977 as a result of a second-phase contract. Thus, the process of defining "how to" translate the network and service concepts into operational hardware and software will be addressed over six months from March to September 1977. Final development and installation is expected to proceed over eighteen (18) months after the completion of the detailed planning phase, placing the system realization sometime in 1980.

Some of the issues under consideration at the time of the October 1976 visit included:

(1) The interface between personnel· and service vehicles. (Decision a to whether servcie personnel ride in vehicles (to load and unload), whether personnel stand by at stops, or how personnel performing other duties at various stops will be alerted to arrival of vehicles requiring manual attention.) The design goal at present is unsupervised, unaccompanied transport.

(2) The layout and type of information to be displayed to the Center Operator and at station stops.

(3) Controlled access to vehicles. (It would not be desirable to intermix patients, "clean" and "dirty" supplies, and visitors.) The current approach is to restrict access to persons with a proper magnetic cards, and to have personnel accompanying patients when using the system.

(4) Design and development of station and central software, computer network, and computer system failure contingencies.

(5) Refinement of vehicle follower technology for stopped vehicle detection and reaction (see Section 5.4.3).

(6) Automated checkout and failure diagnostic procedures and equipment. (See Section 5.3.1.)

(7) Training procedures and maintenance manuals.

(8) Requirements for certification. (Although the Bremen Hospital system will be an urban type of system, it will not be in a public urban area, but on private property.)

A particular observation of interest relative to the Bremen preplanning is the lack of a separate formal "test loop" in the maintenance area, and the lack of a set of "extra" vehicles to maintain peak period operations in the event of multiple vehicle failures. Experience with several systems in the U.S. suggests that such failure contingency planning is necessary for acceptable operation. The manufacturers feel that a separate test loop is unnecessary since the maintenance shop will contain an integration test bench on which vehicle functioning can be tested. It was indicated that further consideration will be given to the need for extra vehicles during the six month detailed planning phase.

5.2 SIMULATION AND PLANNING

Computer simulation has been used extensively in the Cabintaxi program both as an aid to the subsystem design process, and more recently as a planning tool. The original simulation effort at MBB was closely coupled with the development of the asynchronous merge concept and the vehicle longitudinal control system. It has been broadened to include system level simulation of

potential installations in order to exercise candidate system control algorithms, and network reactions. An estimated thirty labor years have been invested in simulation activities, approximately fifteen labor years each on network and detailed design simulations spread over a five year period. The following paragraphs summarize the simulation activity; see Section 4.13 for a more comprehensive discussion.

5.2.1 Simulation as an Aid To Planning

Several dynamic simulations have been developed by MBB to aid in studying optimum network configurations, station capacity, and operational control strategies. A color CRT is used to graphically represent the simulated activity. Hard copy output is also provided. In one simulation, vehicle movement on the network can be observed responding to demand from the various station areas. The vehicle fleet is balanced against demand by dispatching vehicles to or from the maintenance area. Close-ups of key merge areas in the network can be effected in order to obtain a better view of bottleneck situations. In another, blockage density of the network links is indicated by bars which change color as the vehicle density increases or decreases in a particular guideway area. These simulations are composed of discrete elements which represent stations, vehicles, track links, and merge/demerge nodes.

Separate simulations are also used to study a single element in greater depth. For example, the station simulation can be used to study the effects of different station designs on passenger wait times. The number of entry and exit positions, vehicle reserves, vehicle receiving capacity, and passenger arrival rates and patterns can be varied in order to optimize station control algorithms for a particular station. Of course, the control algorithms adopted for a particular station configuration will have an effect on overall network system performance and must, therefore, be ultimately subjected to analysis as part of an overall system dynamics simulation.

The current dynamic network simulations deal only with the small (3 passenger) vehicles. Work is underway to model systems utilizing the larger vehicles (12-24 passengers). The operational problems and strategies may change considerably once large vehicles are introduced, since the current assumption is that larger vehicles may contain passengers for varying destinations.

A cost model has been developed as part of the planning effort. The costs of system operation are computed with this model utilizing estimates of data on the number of passengers carried by the system on a daily, monthly, and yearly basis, average trip length, distribution of traffic during the day, average velocity of vehicles, number of seats and standing positions, etc. The computed costs include energy, material, personnel, investment, and capital expenditures. The data can be reported in various formats including dollars per kilometer traveled, or dollars per person with average mileage per trip. Labor costs include four salary groupings ranging over skills. This model is obviously useful to potential customers in evaluating a Cabintaxi system as a transit alternative. It is planned that the current model will be improved and generalized to cover more systems in greater depth.

A separate simulation tool has been developed by DEMAG to optimize guideway geometry within acceleration, deceleration, and jerk limitations. The resulting guideway geometry, with the proper curve radii and straight line to curve transitions are plotted on a large CALCOMP plotter. This tool should facilitate construction planning and minimize the possibilities that ride comfort criteria as well as particular safety considerations relative to vehicle/guideway interactions do not emerge as problems subsequent to deployment.

Adequate analysis and planning exercises aided by simulation are extremely important to development and deployment of any transportation system. The aforementioned simulation tools are critical to the Cabintaxi effort since the Cabintaxi R&D activity is not aimed at a particular development site or configuration such as were the Morgantown or Airtrans systems, but rather at a modular set of refined technological elements to be combined in sundry fashion to suit numerous applications. Network data for Bremen and for the city of Marl, which were being coded into the data base for simulation studies at the time the U.S. Government team visited MBB, were reportedly completed in December, 1976.

5.2.2 Simulation as an Aid to Design

Other simulation activity has focused on assisting in the detailed design process for system components. The detailed simulation of merges and vehicle platooning has been of special significance in helping to formulate an

analytical theory on the stability of platooned vehicles at merges. The objective of the theoretical work has been to have the effect of the normal perturbation in the speed of platooned vehicles decrease rather than increase. Simulation has borne out the theoretical work on the current Cabintaxi design, and the longitudinal control system has been built to accommodate the results. Simplified simulations of platooning and merging have been developed and validated against the detailed simulations for inclusion in the dynamic network model.

Hundreds of simulation runs were made to study trade-offs between the lengths of the switch sections and the ride comfort factors of acceleration and deceleration associated with the platoon merge process in order to optimize costs. Experiments at the test track in Hagen appear to verify the simulation results at least with regard to the platoon stability. During the October, 1976 assessment visit, demonstrations of the platooned merge were witnessed. The first demonstration consisted of intermixed streams of small and large vehicles merging at the maximum speed of 10 m/sec. The automatic spacing and minimal slowing of vehicles at the merge was clearly evident. Each stream approached the switch at 10 m/sec, merged, and continued as a single stream at 10 m/sec. This was repeated a number of times. No personnel were permitted aboard during the tests because the system lacked provisions for a "fail safe" collision protection monitor, and thus did not comply with safety regulations anticipated for passenger carrying automated transportation. Hence, it was not possible to subjectively evaluate ride comfort during the platooned merge. (See Section 5.4.3.)

5.3 SYSTEM FAILURE MANAGEMENT

5.3.1 Maintenance Automation Aids

Automatic checkout of the Cabintaxi vehicle systems is currently limited to the electronics. In August of 1976, MBB delivered to the Hagen test track the initial model of the longitudinal control and headway assurance test equipment. This automatic equipment can be attached to a vehicle and programmed to step through 120 separate system checks. Each test results in a voltage indication on an attached digital voltmeter. The reading is interpreted by the test technician as a go/no go indication. An accompanying manual instructs the technician on how to proceed in the event of a no go

situation. This test tool is being evaluated and a number of changes are expected as continued use points to needed additional checks or development of better methods for current checks. A comparable unit is planned to be developed for the Bremen hospital system that will incorporate tests applicable to new design features and components added to the control system. It is possible to increase the automation level of this tool, but present plans indicate that this current level of automation is considered by the manufacturer to be sufficient for Bremen and possibly beyond.

5.3.2 Failure Mode Recognition and Data Transmission

Each vehicle can be interrogated in the station via the mission logic transponder. The downlink message contains vehicle ID plus status, such as door open or closed, heaters on or off, vehicle occupied or empty, etc. One bit of the status information contains the condition of a charge cell carried in the vehicle. This cell is charged by odometer pulses or periodically by a vehicle timer. At a preset voltage level, this cell will flag the status bit and indicate to the station and central control that maintenance is due on that vehicle. When the vehicle is available, it will be routed to the maintenance shop for periodic checks of mechanical, electrical, and electronic subsystems.

To date, there has been little emphasis in the design on real-time monitoring of failure modes within an operating vehicle. The implication of the current approach is that transient problems affecting a vehicle's operation may disappear before shop personnel can isolate them. A marginal vehicle could then be placed back into service to disrupt the operation another time. Experience with at least one U.S. system has indicated an even greater need than was originally anticipated for this transient data. A record of which subsystem caused the problem in a control environment of many interfaces and feedback loops is a valuable tool in pinpointing problems. The present Cabintaxi downlink operates only at discrete points along the guideway at demerges and in stations. The addition of a real-time failure detection capability would require either a continuous communication link to the vehicle, or storage of transient data on board the vehicle until transmission could be accomplished. A few vehicle failure categories are already stored and incorporated into the vehicle's downlink message, e.g., overtemperature conditions, transient communications errors, etc.

5.4 COMMAND, CONTROL AND COMMUNICATIONS

5.4.1 Control Hierarchy (Operational Control System)

The control hierarchy consists of three levels. The lowest level is the main safety system which governs vehicles following and stopping, merging, and standby regulation at demerges. This level is largely operational. Several styles of vehicles, large and small, are functioning singly and in groups at the test track in Hagen which includes both merge and demerge switches. See Section 5.3.3 of this report for discussion of open issues relative to implementation of fail-safe operation.

The second level of control is station control, mission logic, and demerge switch control, dealing with ticket cancelling, communication with vehicles, communication with central, inventory control, vehicle lighting and heating, and information governing routing at switches. The station level software was not yet finalized in October, 1976, although most of the anticipated functions were operational in some sense. Ticket dispensing and cancellation machines were functioning at the Hagen test track.

The third level of control hierarchy is central control which is a necessity for controlled and optimal operation in anything but the simplest of shuttles or shuttle loops. The central functions include operator information, communication and coordination with stations, empty vehicle management to assure that vehicle demand can be adequately serviced, vehicle tracking, switch (routing) control information determination and maintenance, operational and maintenance statistics gathering and processing, system failure recovery management, vehicle status display, etc.

While the central control function is not necessary in order to keep vehicles moving from place to place or for safe operation in Cabintaxi design, it is necessary to provide acceptable (from a user perspective) service in almost any network configuration. Without it, bottlenecks can occur on the guideway, particularly in some merge areas, and wait time for vehicles can increase to disturbing lengths. Passenger inconvenience can result from an inadequate or non-existent automatic failure recovery scheme, and such inconvenience could seriously jeopardize the general acceptability of automated systems.

Empty vechicle management strategies and overall central control philosophy were being studied in October, 1976. In general, the strategies under consideration were dependent on information which can be gleaned about the vehicle at switch points in the guideway. Consideration was also being given to the design and implementation of an active vehicle tracking and/or counting system. Ultimately, the system is envisioned to have the capability for dynamic optimum route selection to minimize transit times between Origin/Destination pairs, and to circumvent saturated links, or links in which a breakdown has occurred.

There are several areas to consider relative to central (network) control design, development, and operation.

1) Traffic control algorithm, strategy development, and refinement.

2) Development of operational "applications" software to implement the traffic control algorithms/strategies in a real-time operational environment.

3) Development of real-time operational "systems" software for interface communications and operating system, or executive system functions.

4) Sizing of computer requirements for a particular application (capacity, speed, communications).

During October, 1976, work was underway on the development and refinement of strategies and algorithms for empty vehicle management, traffic control, and network optimization through simulation of operations for several proposed networks for the cities of Marl and Bremen (Section 4.12, 4.13). In addition, work had begun on development of the special-purpose real-time communications software necessary to interface a control (network) computer with the station computers at the Hagen test track. This effort would permit data traffic on the test track network, and automation of the test operation to some extent. Development of real-time application software for implementation of the central computer traffic control algorithms and strategies, and the general subject of computer sizing for a particular application had not yet been addressed. It was suggested that manufacturer-supplied Operating System Software would be utilized for the systems control functions.

By April, 1977, the manufacturer reports that the central/station computer interface is in operation and undergoing testing at the Hagen test track, and that traffic control algorithms for the Marl networks with 62 stations and 1600 vehicles had been demonstrated via simulation (Section 4.13.3.3).

5.4.2 Other Computer Related System Deployment Issues

If the Cabintaxi concept had been deployed as a fully operational network in the public domain at the time of this investigation activity, subjects of particular interest would have included the problems, lessons learned, and experiences associated with specific real-time system implementation, such as: large network inter-computer communication and synchronization schemes; real-time system control software algorithms, software development management, specifications, validation, testing, integration; computer system-related failure detection, input error tolerance, and correction or recovery strategies; overall control system integration, test procedures, and facilities; and attendant schedules, milestone achievements, and labor year expenditures. Experience will be gained in many of these areas with the actual implementation of the Bremen Hospital system.

The fact that Cabintaxi is not designed for one specific application suggests that the operational software, and possibly computer networking approaches, will require tailoring for each new application. It may be possible, however, to minimize the effort, costs, and schedule considerations of tailored operational control software and computer networks through thoughtful modular design and system generation methods.

The software development group at MBB consisted of approximately five persons at the time of the U.S. Government visit, two of which were working on operational strategies, and three of which were specialists in real-time network control.

5.4.3 Longitudinal Control and Headway Assurance Subsystem

The Cabintaxi longitudinal control and headway assurance subsystem is the prime vehicle safety element within the three-tiered hierarcial control structure. It is responsible for vehicle acceleration, deceleration, and velocity profiles including maintenance of vehicle headways in accordance with an established

separation distance criterion. Vehicle operation is asynchronous, i.e., each vehicle adjusts its own speed in order to maintain a given distance to a preceding vehicle up to a maximum speed of 10 m/s. The principal advantanges of this control mode are a capability to intermix vehicles of differing sizes, dynamics, and speeds, and to minimize the impact of normal vehicle operations on the hierarchical control structure. This latter advantage leads to a capability for "graceful degradation" of the system, with the ultimate responsibility for safe vehicle movement resting within each separate vehicle.

The longitudinal control system on board each vehicle requires data relative to its own speed, and the speed and distance of its predecessor to maintain the required separation vs. speed profile along the guideway (See Section 4.2.2.1). Information about its own speed is easy to obtain and is derived from two tachometers located on the vehicles supporting bogie wheels. The remaining data requires a communication link between the two vehicles. The link utilized in the Cabintaxi system is a balanced, lossy transmission line installed along the guideway into which a signal is transmitted by the leading vehicle and received by the trailing vehicle. The amplitude of the signal coupled into the lossy line by the leading vehicle is modulated by its own speed (reduced amplitude for higher speeds). The lossy line additionally attenuates the signal. The result is a signal received at the trailing vehicle whose amplitude indicates either a distant slow-moving or a correspondingly closer faster-moving vehicle. This signal is processed by the trailing vehicle's longitudinal control system together with its own speed into propulsion and braking levels consistent with the separation distance criterion established for the vehicle type. The criterion is predicated on a capability to stop the trailing vehicle prior to a collision, assuming an instantaneous stop (concrete cow on the guidway) of the leading vehicle. The deceleration levels required under these emergency conditions would be approximately 0.5 g to 0.6 g for the three-passenger vehicles.

In addition to the normal antennas needed to implement intervehicle communication (redundant transmit, receive and compensation antennas), a further type has been found necessary. This antenna is called a monitoring sensor, and it monitors the operation of the vehicle's transmit antenna. The sensor is located downstream of the transmit antenna and can detect malfunctions in the transmit circuits, as well as breaks in the wayside lossy communication cable.

A fail-safe comparison circuit in the vehicle provides the indication of malfunction. This signal can be used to stop or otherwise affect the vehicle's mission. There are similar fail-safe comparison circuits in other portions of the longitudinal control system, such as brake and propulsion controls where failure has an implication on safety. The benefits of redundant communication paths between vehicles is only present in "free track" areas, not in merges, demerges, or stations. Therefore, stopped vehicle failures in these areas have a much higher probability of producing a "dead vehicle". This probability, plus consideration for additional failure modes determined through an almost continuous failure mode and effect analysis, have prompted MBB to consider an additional level of collision protection for each vehicle.

Development philosophy up to this point has stressed operational designs capable of extensive testing at the Hagen test track in order to determine or refine engineering parameters. This new level of fail-safe collision protection is representative of the additional engineering required to develop the safety assurance considered necessary for a publically deployable transportation system.

During the development of the vehicle control system, talks were undertaken to determine the safety requirements which would be deemed necessary by the proper authorities to allow such a system to operate within Germany. A redundance only based vehicle safety system was determined not to be sufficient. Therefore, development of a collision protection monitor which operates on a fail-safe principle is required prior to deployment. The Institute for Rail Technology of the TU in Braunschweig has been considering several potential technologies applicable to the development of a fail-safe collision protection monitor. The selection of a single system among these possibilities should take place in the summer of 1977. The subsequent design and integration tasks are expected by the manufacturer to result in a fail-safe monitor available for test at the test track in Hagen in the spring of 1978.

5.4.4 Vehicle Mission Logic

Mission logic is that portion of the vehicle control system that stores destination data and responds to switching and door commands issued by the wayside control at demerges and stations (See Section 4.2.2.2). The transmission bandwidth between wayside and vehicle is 50 KHz, with a carrier

frequency of 5 MHz for uplink, and 8 MHz for downlink. This mission logic and its accompanying transmission channels are considered by the manufacturer to be fully operational.

There are presently only discrete transmit/receive units in the guideway and in the stations. These units (transceivers) are used in the station berths to transmit to the vehicle (uplink) destination data and receive from the vehicle (downlink), status information. At demerge areas in the guideway, the vehicle will downlink its stored destination to the transceiver unit which has as a portion of its control logic a list of all possible destinations and the correct position of the switch wheels for each. The transceiver unit will then uplink a left or right switch command to the vehicle. The physical switch is accomplished on the vehicle through outboard motion of a left or right mechanical arm. In its extended position, the arm will be captured by a static sleeve on the guideway directing the vehicle along the proper path. The list of destinations and switch positions stored by the transceiver unit will be replaceable by the system central control, should route modifications be necessary. A back-up hard-wired list is also stored in the transceiver unit in the event of central control malfunctions.

A portion of the 50 KHz mission logic bandwidth has been utilized for an additional 6-tone command structure to couple track information to the vehicle. The six tones range from 300 Hz to 4 KHz with a three out of six code allowing 20 separate commands. Depending on whether a vehicle is in a free track area or a station, merge or demerge area, these tones control brake rate limiters and turn on or off the left or right redundant inter-vehicle communication transmitters.

The mission logic link is also being considered to uplink the data necessary to achieve vehicle closure when the automatic pushing of a disabled vehicle is necessary. The closure technique would involve a communication between central control and the trailing vehicle which would override that vehicle's headway assurance system, allowing it to proceed at a slow speed until it couples with the disabled vehicle ahead. There are two important implications to this use of the mission logic communication link. The first is a new requirement to be able to communicate over the entire guideway. The present configuration consists only of discrete transceivers in station, merge,

and demerge areas. The second is a safety consideration relating to the override of the headway assurance system. The addition of this capability thru the mission logic link necessitates a comprehensive design analysis to assure that there is no compromise of either the pushed or pushing vehicles' safety systems. The manufacturer recognizes that public use requires this design be accomplished in a fail-safe manner, and has indicated that a concept for fail-safe design has been formulated.

The mechanical coupler to be used in the emergency pushing operation has been developed and was undergoing tests at Hagen during October, 1976.

5.4.5 Merge Control

The realization of the asynchronous merge was a significant achievement in the Cabintaxi development program (see Section 4.2.3). Its implementation in hardware was preceded by a large amount of computer simulation and analysis to assure that proper flow rates could be maintained throughout the merge region.

The concept requires that each vehicle on a merging branch be aware of the other's presence. The implementation technique is to partition one side of the lossy communication cable in each leg of the merge into a number of two meter segments. As vehicles enter the merge, a virtual image of each vehicle is transferred to a segment on the opposite leg. Depending on the position of each vehicle on its own track leg relative to the vehicle on the other leg of the merge, one vehicle will see the virtual image ahead and slow down to allow the other vehicle to enter the merge first. The signal transfer is accomplished through an electronic circuit that provides both gain normalization and logic functions. The logic is used to determine which vehicle is prime and which is secondary. A reed relay in each leg of the merge triggered by a permanent magnet on the vehicle provides the input to this logic. The logic input drives an electronic switch that selects the segments which must be activated.

The selection of a particular segment is only made for the first 30 meters of a merge (called the soft part) in order to achieve a more gradual slowing of the secondary vehicle. The remaining 30 meters (called the hard part) is connected through compensating amplifiers to specific segments. The electronics

that make up this logic and amplifier network are complex, not redundant, and have a large impact on system safety.

The presently designed electronic package currently operating successfully at the Hagen test track is expected to remain basically unchanged for deployment. However, some additions have been suggested which will allow monitoring of the operation of the merge electronics. The extent of these checks and the degree of monitoring required had not been determined at the time of the assessment.

A redundant overlay on the last few meters of the merge is currently operating at the Hagen test track as secondary protection. This technique involves detection of conflicting vehicles approaching the merge frog. The detection process utilizes additional reed switches in the guideway to determine if a conflict is about to occur. If a conflict is detected, a high level 100 KHz signal is injected into the non-segmented lossy communication line associated with one of the vehicles. The vehicle's headway assurance system will suddenly "see" a vehicle immediately ahead and brake to a stop. This secondary protection is a simple technique designed to achieve redundant merge protection. The implementation at the test track is not fail-safe; however, it appears reasonably simple to make it so. A proposal for a fail-safe monitor for the secondary merge protection has been formulated and given to the TU in Braunschweig for their evaluation and approval. It is anticipated by the manufacturer that the TU will approve the design in time for a planned test in the spring of 1978. The combination of failure monitoring of the merge electronics plus a fail-safe back-up, should a conflict develop, appears to hold promise for implementing a safe asynchronous merge.

5.5 SYSTEM TESTING HISTORY

The present Cabintaxi/Cabinlift system is the result of development which began in 1969.

The long development phase which still continues has allowed the system to reach a high level of sophistication before going into public service to any large extent. In this way, risks, especially financial ones, are diminished. Of special value for the Cabintaxi development was a large, well-equipped test

facility near Hagen on which the system and its components could be tested under essentially realistic conditions.

The technical development was accompanied and to some extent influenced by theoretical research (for example, public acceptance studies), as well as project and application studies.

In the following discussion the procedure for the technical development will be discussed. In this connection the following concepts will be used:

Concept		Example
System	:	Cabintaxi/Cabinlift systems. . .
Subsystem	:	Vehicle, guideway, station, control. . .
Components and/or Construction module	:	Propulsion, head-way spacing. . .
Parts	:	Wheels, head-way measuring cable. . .

ABBREVIATIONS

EPA	Testing facility near Hagen
BM I, II, III	Models I, II, III
TÜV	Technical Safety Administration
GfK	Glass fiber reinforced plastics
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
EMV	Electromagnetic tolerance
HF	High frequency
PDP 11/15	Mini computer from the Digital Equipment Corporation
ABS	Acryl-butadien-styrene mixed synthetic polymer
DÜ	Data transfer
FZ	Vehicle

5.5.1 Development Methodology

Fundamentally, there are three phases to technical development:

1. Analysis and concept phase,

2. Component development phase, and

3. System testing phase.

A fourth phase, the demonstration of the system, including the preparation, construction, and operation of the system in a real application has yet to be fully realized.

In the analysis and concept phases, possible implementation concepts for the Cabinrail system, its subsystems and components were worked out.

The result was a prototype which was built to a large extent on available technology (for example, use of LIM), but which also provided for the development of some new components (for example, propulsion and head way spacing). Since no specifications for such a prototype existed with respect to requirements for safety and operation of automatic local transport systems, other available guidelines were referred to, such as those for existing public transport systems, TÜV requirements (for example, those applying to passenger cars), industrial regulations (DIN), and military guidelines.

On the basis of technical trials on the test bench during the component and development phases (beginning in 1971), the basic technical concepts of the Cabintaxi were determined: running surface, bogies and logic construction, propulsion by means of a linear motor, head-way spacing system, and passive switching. These concepts have remained unchanged.

The technical development process of components and the entire system took place in further laboratory trials and through test runs at the Hagen test facility (system testing). (See Figure 5-1)

Every component was subjected to a constant iterative process of modeling, testing, modifying, and when necessary, new modeling with repeated testing of the modified component. After sufficient development was obtained through laboratory testing, the installation of the component at the test facility was carried out. In the system testing at the research facility, the components were subjected to loads and stresses encountered in real operation. Investigation was also made into influences which remained unconsidered during laboratory testing. The results of the trial runs have, to a great extent, made further test-bench trials necessary so that the development proceeded repeated cycling between test-bench trials and whole system testing. The following could be listed as important test objectives.

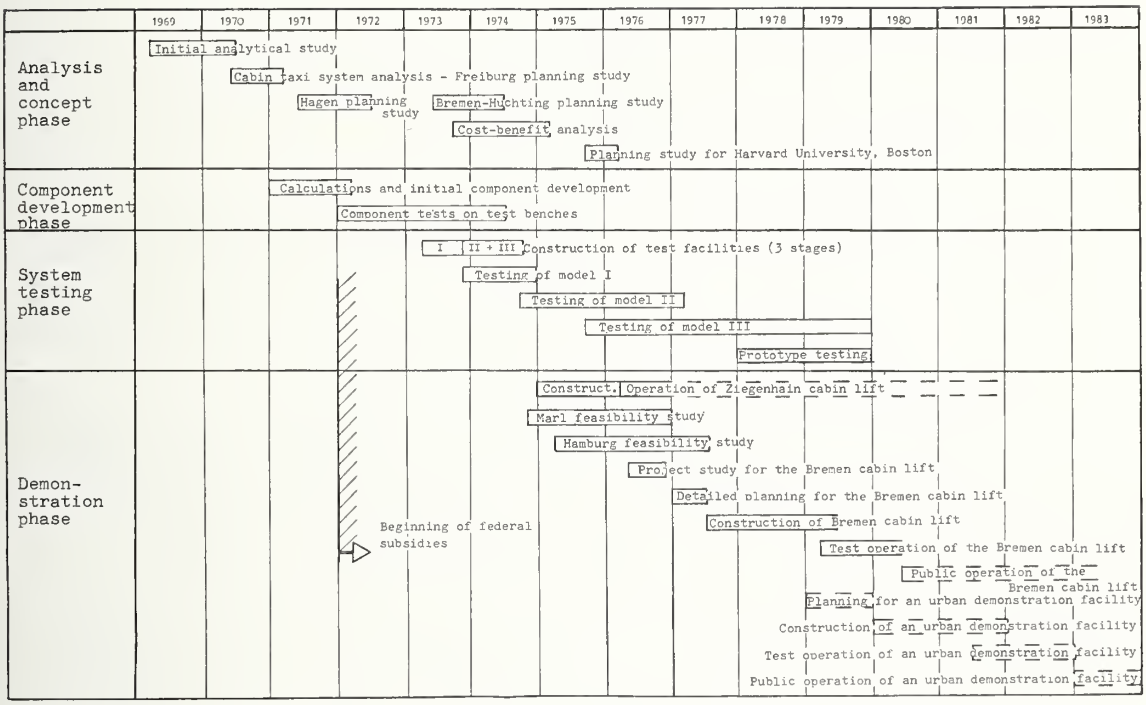


Figure 5-1. System Test Cycle

Test Objectives

Accumulation of measurement data on which to base a model design,

Compatibility within the subsystem,

Simple technical realization (costs),

Safety,

Life span, (Reliability)
(costs in money and personnel),

Comfort, and

Environmental impact (exhaust gases, noise,...).

Technical Modifications

Modifications for improvement of the components were undertaken in the following manner:

Rejection of a concept, new model and/or use of another principle,

Modification of the concept,

Installation of the substitute equipment and detail modification (for example, with regard to material).

The initial sequence of component development was selected in order to fabricate a test facility: for example, guideway, power plant, bogie, vehicle, and suspended track components. Upon completion of the first parts of the test facility, system testing began. The further development encompassed the goal of producing small transport networks with several vehicles, as well as test systems suitable for long-term evaluation. This was made possible by the manufacture and testing of component switching, headway spacing, stations with assembly equipment, and maintenance equipment. Along with the ongoing component development, in 1975 components such as those that will be used in more complex systems (for example, the Bremen Cabinlift) were included.

Much of the component development is nearing completion, with activity continuing primarily in connection with optimization of current performance levels (e.g., increasing wheel life, longer in-service time for power collection brushes), or for lowering of production costs (e.g., vehicle and mission logic transfer). Some system elements are in early stages of development, such as the central control of complex systems.

5.5.2 Cabintaxi Test Facility

Construction of the test facility was begun in Hagen in April, 1973. It has met the requirements laid down for whole system testing.

The system testing serves to determine the functional capability of the system with regard to the interplay of the components under realistic operational conditions, as well as to evaluate reliability through long-term testing.

The test facility has been expanded stepwise since the beginning of operation on 9/6/73, and, at present, is equipped with 11 switches, 3 stations, and a maintanance shop (Figure 5-2).

Station 01, like the maintenance shop, contains two levels to accommodate the double track (suspended and supported vehicles). The upper level is accessed by means of a stairway. The station is equipped for testing operations with two completely separated control systems for the supported level and the suspended level. Both levels are equipped with magnetic card machines. (See Figure 5-3.)

Station 02 is elevated and accommodates only suspended cabins. It is equipped with an elevator as well as a stairway. A so called "lift control" (destination selection by push button) is installed in this station (Figure 5-4).

Station 03 is situated at the beginning of a 15% incline (suspended rail), and is fitted with a single platform having two elevations, one for operation with the standee-only vehicle (Cabinlift). (See Figure 5-5.)

The guideway consists of 560 m of supported, and 901 m of suspended guideway, certain sections of which are double. It incorporates the most important track characteristics: straight sections with a 40 m span width, curves with a 30 m as the smallest radius, spirals, guideway camber of 5 degrees, and a special incline (grade) of 15%.

The chronology of main activities at the test facility are listed below.

September 1973:

1. Construction Phase

   About 150 m of double guideway, one switch per guideway level, one station, and two vehicles.

   Checking of the function and the components such as bogies, truck, switches, and their function in the unit. In addition, external specialists investigated noise levels in the vehicles and along the track. Research as to the operational performance, testing of passenger safety in the cabin, and evaluation of the important load parameters were made as a basis for statistical calculations.

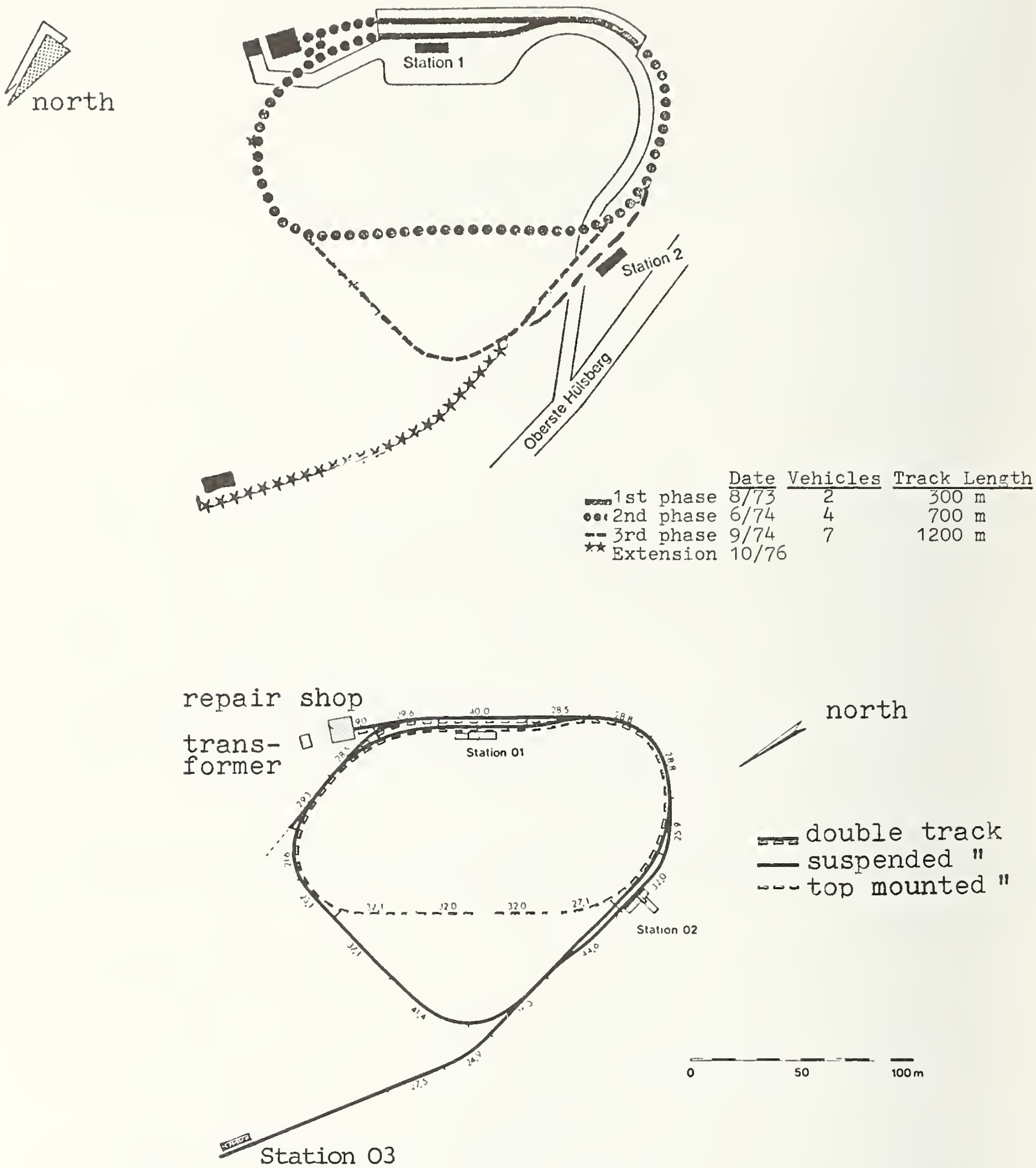


Figure 5-2. Hagen Test Facility

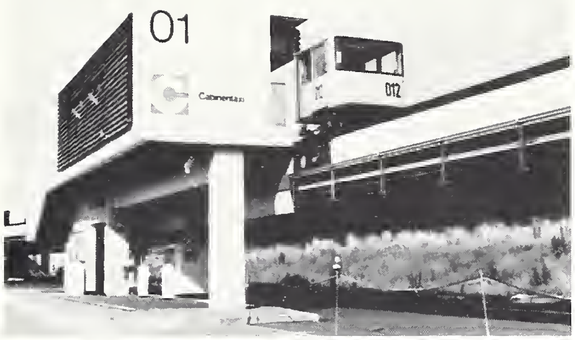


Figure 5-3. Hagen Test Facility Station 01

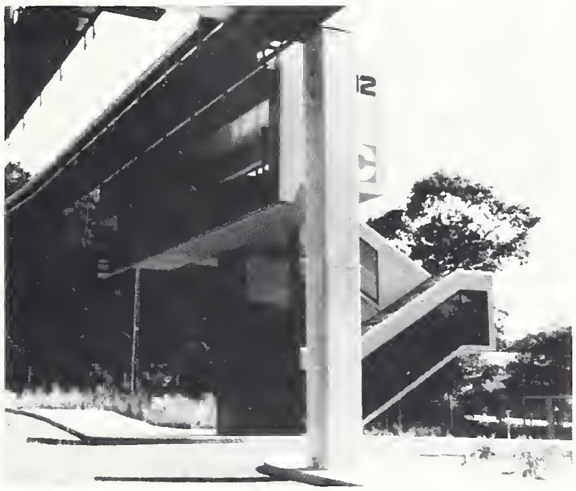


Figure 5-4. Hagen Test Facility Station 02

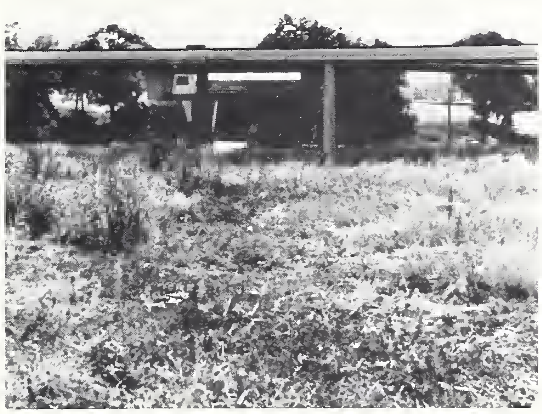


Figure 5-5. Hagen Test Facility Station 03

June 1974:

2. Construction Phase

Expansion of the faility to a supported guideway length = 550 m; installation of the maintenance shop.

System testing of the automatic operation, especially with regard to automatically controlled trip to a specific destination, headway spacing between vehicles, and the unmanned passenger check-in and trip ticket machines. Research with regard to improvement of passenger comfort. The first long-term test under realistic operating conditions, that is with stops, waiting periods, and starting over again in certain areas of the guideway.

Expanded psychological tests for evaluation of passenger behavior.

Fall 1974:

3. Construction Phase

Expansion of the existing guideway loop to include a longer suspended track.

Testing of the automatic operation, as well as improvement of passenger comfort.

Middle 1975:

Construction of off-line Station 02.

January 1976:

Beginning of long-term testing of the 12-seat vehicles.

Between the middle of 1975 and the middle of 1976 studies were conducted with respect to the improvement of passenger comfort, pay load, and noise measurements at the suspended track level. Tests were also carried out with regard to longitudinal control, merging, and spacing of the vehicles, as well as measurements of vehicle oscillation and voltage levels.

Long-term tests for the evaluation of the reliability of the components were carried out. These lead to modifications, especially with respect to the head-way spacing cables, vehicle suspension, and power pickup.

Fall 1976:

Automatic vehicle platoon, platoon merging runs, and recovery of stalled vehicles.

October 1976:

Construction of the 150 m long suspended track expansion with 15% incline, as well as the construction of Station 03.

For 1977 the following are planned:

Runs with increased speed up to 50 km/h, determination of the reliability of automatic components, determination of the long-term integrity of mechanical parts, improvement of passenger comfort, improvement of the lifetime of parts subjected to wear, such as wheels, power collectors, etc.

5.5.3 Test Results

The development of the Cabintaxi was accomplished based on a large number of varied tests and testing activities. Different types of tests were carried out in a step-wise development by the manufacturers, external specialists in laboratories, on test benches, and at the test facility near Hagen; for example, dynamic vehicle stress tests, load and energy use measurements, material tests with regard to function and wear performance, and fire safety, long-term tests for the evaluation of component wear, maintenance and reliability tests, crash testing, noise measurements, etc.

5.5.3.1 Vehicle Development

The vehicle is constructed from a large number of individual components, each one of which has been subjected to an iterative development process.

A large part of the vehicle development is reflected in the three models which have been finished to data (BM I through III), which differ mainly in the construction of the cabin. However, modification of any components such as the propulsion, suspension, door systems, and control electronics, etc. were also considered in the preparation of the new types of cabins. Using parts from the KK3 cabin, and on the basis of the modular construction principal, the cabin with two bogies for 12 passengers (KK12) was built. In total, 18 cabins of different design and size have been finished to date:

- four small cabins of design I (two of which have been used in crash testing. The other two have been dismatled),
- six small cabins of design II (one of which has been used for crash testing),
- four small cabins of design III,
- one large cabin with 12 seats,
- one cabin for Zeigenhain Cabinlift,
- a service vehicle for the Ziegenhain Cabinlift, and
- a maintenance and recovery vehicle for the test facility in Hagen.

In the time period between June 1975 and June 1976, the Cabintaxi vehicles have achieved the following performance record on the test facility near Hagen. Endurance tests and long-term tests were occassionally carried out in extreme weather conditions (storms, snow, frost):

Mileage	200,000 km
Switch functions	650,000
Brakings	420,000

The following deals with the development process of the vehicle components, the cabin frames, vehicle doors, suspension elements, running wheels, and power to the switching wheels. Measurements with regard to energy use are also included. The development of components is summarized in Section 5.5.3.9 (Summary Tables).

5.5.3.1.1 Cabin Frame

Plastic (fiberglass) as the material for the cabin was rejected early, in favor of an aluminum-type construction. The aluminum construction underwent two cycles between the test bench and full system testing.

The BM I/II cabins had inadequate strength in spite of reinforcement of the corners with cast pieces and, in the case of the BM II, additional coupling parts. This led to a new design for the BM III cabin. The newly developed cabin construction was prefabricated in individual pieces which were bolted together during final assembly.

Successful test-bench trials led to the building of five vehicles of the BM III type (including the KK12 vehicle with 12 seats). These were successfully tested at the Hagen test facility. This construction principle is the basis for the development of the larger vehicle, for example, the Cabinlift.

Changes in construction approaches of the type described above, whereby full development of the plastic cabin construction was dropped in favor of bolted aluminum prefabricated construction, were common in the development of several components, especially in the initial phases.

5.5.3.1.2 Vehicle Doors

The objective of the door testing was to select a door from those offered by the different manufacturers which was especially suited to the cabin system. On the basis of comparable functions tests, two different types of sliding doors were selected.

Several modifications were required during installation into the BM I cabin. These test, selection, and installation phases applied to the test-bench trials of other components as well. In the whole system tests which followed at the EPA, none of these doors proved to be suitable even after modification. Therefore, the concept of the collapsible sliding door was abandoned and another principle, that of the simple sliding door, was adopted. Even with this new construction, however, several problems arose during function and stress testing. After correction of the weak points, the door of the BM II vehicle was subjected to whole system testing at the test facility. Additional parts were required before this component performed satisfactorily in function and load testing, as well as in extended period testing in the BM III vehicle. This component had cycled through the iterative process of test bench to whole system testing three times before reaching the present state of development.

In addition, two different models of fully automatic sliding doors have been developed and are now in use in the Cabinlift in Ziegenhain and on one KK3 vehicle at the test facility. These doors have been in use for a long time and perform satisfactorily.

5.5.3.1.3 Suspension Elements

A vertical spring was installed between the bogies and the cabin in vehicle models I and II, (Figure 5-6). From the results obtained on vehicles 005 to 009 of the BM II type, it was clear that the vertical spring would have to be augmented by horizontal springing. Having had good test results with pinions made of spring steel, a (gimbal) joing was designed as shown in Figure 5-6(3). Furthermore, a contract for development was awarded to the Porsche Firm for the suspension system in Figure 5-7 which was to be tested in the BM III type vehicles during 1976.

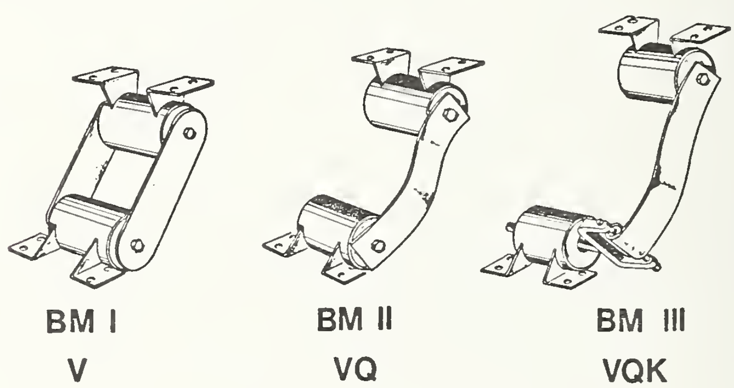


Figure 5-6. Suspension Systems

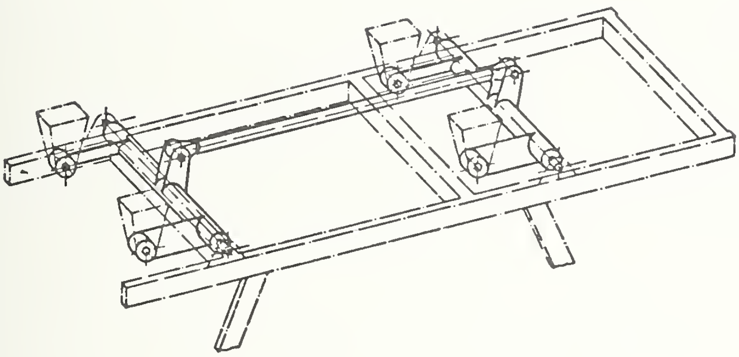


Figure 5-7. Suspension System of the Cabin Bogie (from Porsche AG)

5.5.3.1.4 Running Wheels

Pneumatic tires with high pressure inflation, solid rubber tires, and wheels with vulcanite plies were all tested as possible running wheels for the Cabintaxi vehicle. During laboratory tests solid rubber tires appeared suitable. During initial trials at the test facility, however, these tires installed on BM I attained only 4,000 km, which was deemed unsatisfactory performance. Exact adjustment of alignment and stops in subsequent models, as well as higher precision in finishing the rotating parts, modified rubber formulas, and a modified profile improved the performance by 1976 to 30,000 km. Further improvements in the rubber formula have increased the performance to 40,000 km at present. The manufacturers target is for 1-year service which would entail approx. 60,000 km.

5.5.3.1.5 Control for the Switching Wheel

For activation of the rods which control the switching operations, electronically driven poly solenoids were used with good results. An unfavorable

effect due to wear after some 100,000 switching operations, however, raised some questions concerning this component. Therefore, an alternative hydraulic switching unit was installed in two 12-seat cabins which were also under test at that time.

5.5.3.1.6 Energy Consumption

Energy consumption of the vehicles was measured at the test facility during the fall and winter of 1975-1976 under realistic operating conditions. Station intervals were an average of approximately 500 m, and runs without stops were considered. As Figure 5-8 illustrates, the specific watt-hour per seat-kilometer value is dependent on the size of the cabin, and to a lesser extent on energy used for heating. Further measurements on energy consumption

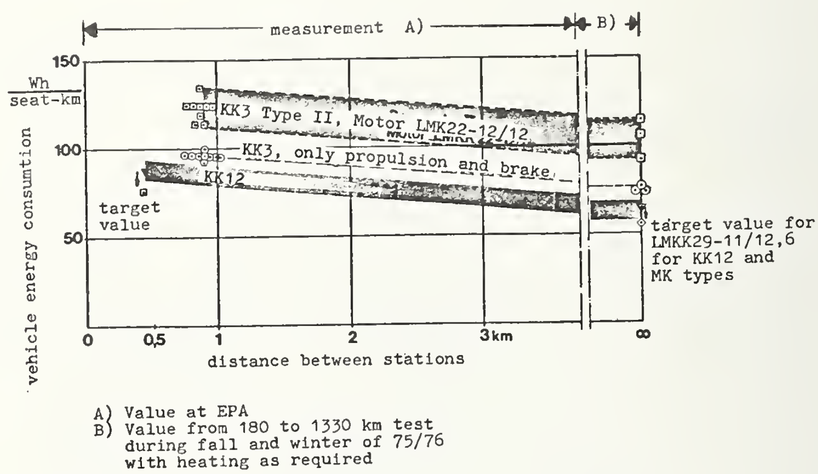


Figure 5-8. Energy Consumption

followed in the fall of 1976 at the test facility with a suspended KK12 cabin. The measurements were made for uninterrupted runs, as well as for run/break/stand cycles during station stopping, and at different gross weights (empty/500 kg/1000 kg payloads). The operating speed was 10 m/s, and the cabins were not heated. With heating on maximum, the energy consumption will increase by

12 Wh/seat-km. The target value for vehicles without a load for station intervals of 500 m - 1 km is 50 Wh/seat-km. The results were approximately 15% over the target value. For vehicles with loads of 500 kg - 1000 kg, the results were 40 - 50% over the target value. The manufacturer feels that the energy consumption should be reduced to the target values by 1979. A 20% reduction in energy consumption is expected through an improvement of the propulsion system.

Experiments have been undertaken to evaluate the effects of load, cabin heating, characteristics of the track, cyclic operation, and acceleration and deceleration of energy consumption.

5.5.3.2 Headway Measuring System

The development of the headway measuring system for the Cabintaxi, aside from the transmitters (couplers) and receivers installed on the vehicles, included the improvement of headway measuring cables along the track. The cables are used when several cars are on the network for vehicle interactions during headway maintenance and merging operations.

The coupler, and especially the headway measuring cable are typical examples of components for which the application of new concepts were required, after having attempted improvements on the original ideas.

After laboratory testing had shown that such a system could be developed, a wide range of tests were initiated on a large closed-loop test bed. Redesign of the coupler and cable was undertaken after several modifications during system testing with five vehicles at the test facility, and sensitivity to weather and environment, led to unsatisfactory performance. The design was changed from a double cam to a single-cam system for the couplers and cable, and improvement of the contacts between the copper line and the carbon runner on the cable were made. The measuring cable, which consisted of copper bands and a carbon runner, was replaced by a newly developed cable having discrete resistors.

After further modification resulting from whole system testing at the EPA, this design performed satisfactorily during platoon and switching operations, as well as in fully automatic operation.

The development of the merge and demerge multi-vehicle switching was strongly affected by the function of the headway measuring cable. While the function tests of the switching electronics were satisfactory in principle, strong feed back effects were experienced in the beginning because of the inhomogeneity of the cable. In connection with the redevelopment of a cable with discrete resistors, the switching electronics which were still suscep- table to interference had to be reworked. After several modifications indi- cated from function tests, satisfactory performance was obtained during whole system testing at the EPA.

Simplification of the merge control electronics is still a target in the present development.

The headway measuring system is an example of a redevelopment project for which testing activity was especially concentrated. The development is to a large extent complete except that development and installation of a fail-safe monitor is still necessary to comply with German safety regulations.

5.5.3.3 Data Transfer

Electromagnetic interference played a role in the data transfer testing for vehicle and route-installed electronic elements. In laboratory tests, generally favorable functional operation was obtained. Maintainability was not addressed at that time. In whole system testing with full BM II vehicles at the EPA, rework of the circuits was found to be necessary, particularly because of impulse interference. The route data transfer elements were relocated in the stations for improved maintenance.

After further modifications of the vehicle components resulting from function testing (to correct interference problems in the computing circuits), further long-term whole system testing was carried out with 10 vehicles. This resulted in problem-free interaction of the vehicle/station control link.

The development of these components was relatively problem-free. After the first cycle through the test-bench/whole system procedure, and after basic modifications in some elements of the system, a second cycle left only a few minor problems to be corrected. The development is complete and the components will be used in their present form for the Bremen project.

5.5.3.4 Station Control

Tests of the station control system gave good results during the first functional testing. The computer, however, was susceptible to interference. After modification of the computer interface (data multiplexer), the station control system was installed in station 01 for the purposes of whole system testing. The environmental temperature in direct sunlight proved to be too high. In spite of the installation of a climate control system, a new design concept (BM II) with a different type of computer was required to obtain the necessary reliability of control and operation.

Functional testing in the laboratory, as well as the whole system testing, proceeded satisfactorily (both stations at the EPA were fitted with new computers and the BM III type vehicle). A large number of software modifications resulted from the research and system testing operations.

The testing phase has advanced to the stage where research with regard to the interplay between the network computer and the stations can begin (1976).

The development of the travel ticket machines included correction of some developmental errors, as well as modification to operational elements and the electronics, resulting from system testing. No further modifications followed. For a Cabinlift system such as the one in the Bremen project, however, a simplified operational unit is required: for example, the one in station 02 after modification to push-button operation ("lift control").

5.5.3.5 Power Rail - Power Collector System

The requirements of the Cabintaxi were such that the best solution for energy supply was by means of 50 Hz alternating current with a maximum voltage of 1000 V. For the first construction phase of the test facility in Hagen, the double-T formed copper concaved profile was selected. The cross sectional area of 240 mm^2 was dictated by the energy supply at the test facility.

As a safety measure against excessive operation voltage, a shielded cable system was installed.

The flat contact surfaces provided a simple and safe connection with the power rails on straight stretches, as well as on curves with the required minimum radius of 30 m.

The appropriate power contacts on the vehicles are situated on either side of the bogies; to accomplish switching and branching operations, the power contacts are brought into operation on one side or the other.

The operational safety with respect to the performance of the electrical insulators and protection against short circuits in the system was tested for the total power rail - power collector system. The AC voltage and current spike testing of the insulation materials were tested by the materials testing facility in Dortmund. The alternating voltage testing was carried out according to specifications by applying a 50-cycle alternating voltage of 10 kilovolts for 1 minute. This was done once between the power rails and again between each power rail and ground. The short circuit interval was 0.2 seconds. As a high current test, the highest tension which could be applied before the beginning of arcing was calculated. The testing was carried out to a value of 28 KA.

Further investigations were undertaken to determine the noise levels during operation inside and outside the cabin. Noise levels were measured in the cabin and outside of the vehicle at 2 m and 8 m distances from the track at a speed of 3 m/s.

It turned out that with decreasing distance from the tracks, the individual types of noise levels change in different ways. At a distance of 8 m, the power rail noise determines the overall noise level. The impulse type noise created by passage of the power collector enters the frequency range more than about 300 Hz above the general in-motion noise level.

On the basis of information resulting from test runs in the first construction phase, targets for the power rail and power collector were increased.

The more stringent objectives such as

- Limiting the noise at a distance of 1.5 m from the track to 60 dB(A) at a speed of 10 m/s.

- Current loading to a maximum of 3000 A
- Manufacture of technically simple power collector

  led to modification of the power rail.

The power rails are now made of a symmetrical double-T convex rail with AlMgSi as a conductor. To accomplish self-damping, large mass is concentrated in the area where the power collector makes contact. The contact surface for the power rail could either be made of the conductor mentioned above, a flame-sprayed copper plating, or steel plating.

The same requirements for noise abatement apply to the power collector and the power rail. In addition the following objective were set:

- Resistance to motion (mechanical friction) per cabin = 4 kg total force.
- Total reaction force on the vehicle = 25 kg.
- Weight per power wiper = 10 kg.
- Installation volume 300 x 260 x 260 mm
- One year service life = 60,000 km

Therefore, the power collector was redesigned and several alternatives were tested under contracts.

In 1976, in addition to the EPA facility, a circular multi-purpose test track having a 13 m diameter was put into operation (Figure 5-9). Aside from propulsion and braking tests, intensive testing of the power rail blocks and evaluation of the friction characteristic of the power collector could be accomplished through long term testing.

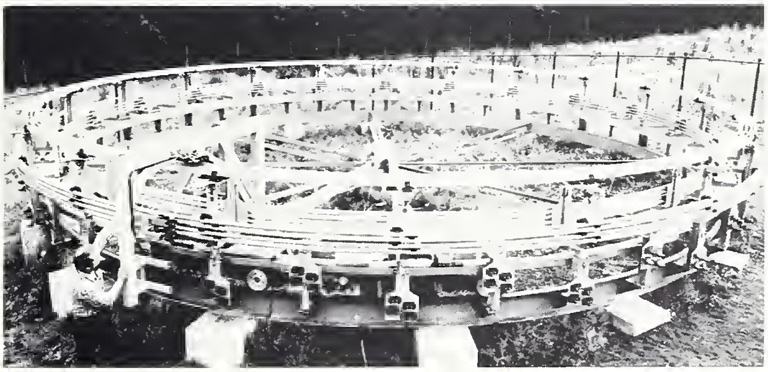


Figure 5-9. Circular Test Track

The test procedure during long-term testing was representative of actual conditions, that is, with stops, standing intervals, and starts after about 700 m (average station interval).

With precision power rail blocks and rails of aluminum with a contact surface of steel, the present power collectors with metal impregnated carbon as contact material have a service life of over 40,000 km, and will probably exceed the anticipated life of 60,000 km.

Further improvement of the power rail - power collector system is being sought continually.

5.5.3.6 Electromagnetic Interference

The Cabintaxi development program has had the benefit of a large and well equipped test facility at Hagen where preliminary designs and operational concepts can be proven in a reasonably normal simplified system environment. Use of this facility plus the normal subsystem and component level testing performed by MBB has resulted in a highly iterative development process capable of addressing almost all engineering questions in the design of the Cabintaxi command and control system.

The preliminary step in the design activity centered on the selection of components and the development of an interface specification. The characteristics of all interfaces were defined and requirements were levied relative to sensitivity and form. The resulting command and control system design utilizes mostly single-ended open collector techniques for the digital interfaces, and dual differential lines for critical analog signals.

Electromagnetic noise minimization was a consideration in all designs. An initial analysis and test of internally produced noise compared the most sensitive elements in a functional block with the most noise-producing elements in that block. The main sources of electromagnetic noise in the vehicle were:

- the SCR voltage controller for the linear reduction motor and the eddy current brake,
- the power pick-ups,
- the switching-mode power supplies,
- the headway signal transmitters, and

- various relays and switches, e.g. the solenoid for motor reversals and relays for the door opening commands.

The components most sensitive to noise were the communication links for headway and mission information, since both are rf systems of relatively large bandwidth.

The EMC analysis confirmed a problem with chopper-operated power supplies and, as a result, a change to a silicon controlled rectifier-type was made. As each functional block design was completed, a lab model of that block was subjected to an electromagnetic interference test in MBB's test chambers. The levels of interference were not defined in the traditional MIL SPEC manner, but predicted on levels expected in normal operation.

Initial test levels were very high and were refined as more data became available from the component's measurements and from the test track.

The two major communication links (mission logic and headway data) have been extensively analyzed and tested. The 8 and 5 MHz mission logic links required extensive changes during the test program. Initial attempts at filtering and shielding were unsuccessful, and a new design had to be implemented. The test track experience has indicated no problems with this most recent design, allowing for additional margins in the levels of noise produced by other components.

The lossy communication cable used for vehicle-to-vehicle headway data has been modified, but only due to manufacturing and installation difficulties. The cable is highly attenuated and balanced to reject common mode noise. Therefore, it is not subject to many noise problems. The prime noise source affecting the cable appears to be eddy currents in the linear induction motor reaction rail. These eddy currents influence the transmitted signal in the cable and are a source of noise to the vehicle's receiver. The level of eddy current interference appears to be quite low, but is being monitored to assure that it stays low.

5.5.3.7 Environmental Considerations

All systems developed for Cabintaxi have been designed to operate in an external environment of -25°C to +35°C. This is a system-wide goal applied

to all components. The electronic subsystems have been designed to operate between -25°C and +60°C. These temperature ranges have allowed the use of almost all "commercial grade" components. Only a very few selected MIL SPEC devices are utilized in the construction. The high temperature end of the operating range appears to present few problems. However, some components must be heated to allow use at the -25°C end. Humidity and moisture tests have not as yet been done and will await the final packaging design. Because the electronic packages are mounted to the sprung mass (cabin compartment) of the vehicle, vibration testing has been considered of less importance, but will be carried out in 1977.

5.5.3.8 Failure Mode Analysis

Reliability and failure mode predictions have been undertaken for all electronic components developed by MBB, as well as the propulsion controller developed by DEMAG. MIL data on components, connectors, derating factors, etc., have been utilized to determine an MTBF for each functional block of the system. The test program currently underway has as one of its goals, the gathering of data to support these predictions. Failure mode and effect analysis have also been undertaken on each functional block in order to determine potential impacts on safety and operability.

The development of a longitudinal control and headway assurance system requiring active communication between vehicles necessitates that considerable attention be paid to potential failure modes and system tolerances. The development program is paced in such a way as to allow analysis, test, and manufacturing experience to feed back to designers for modifications to system concepts or implementation techniques.

Original design specifications were based on a loose combination of military and "normal" industrial standards revised, as necessary, to fit the projected requirement of a new automated transit system. One of the prime outputs of this development program will be the assessment of the reasonableness of the subsystem specifications through an iterative process of design, test, and deployment experience. The result is expected to be definitive set of design, fabrication, and performance specifications tailored to the safety and operational requirements of AGT systems. The process of assessing the

design is a continual one and has resulted in a vehicle control system that has been implemented in stages. Some major subsystems are composed of mature and tested designs, while other major elements are now only in the early design phases.

The lossy line used for communication between vehicles is an example of a mature system element that has required redesign to simplify the manufacturing process. The original continuous impedance balanced lines were brittle and often became open during installation at the test track resulting in the potential loss of headway assurance communication between vehicles. The communication lines are redundant on both sides of the guideway limiting this effect; however, the incidence of cable breaks was sufficient to consider a probability of loss on both sides. The solution was to implement the lossy line design using three continuous copper strips with discrete resistors every 10.0 cm to achieve the required damping constant. The lines and resistors are encapsulated in a plastic sheet and installed in the guideway backed up with discrete ferrite rods to complete the vehicle transmitter's magnetic coupling circuit. The tolerances between the presently designed vehicle antenna and communication cable are quite tight, and new vehicle antenna designs are under consideration to increase the margin for alignment and motion errors. The effects of air gap variations on the signal within these ranges have been minimized through the use of a magnetic feedback circuit on the transmitter/antenna subsystem.

This type of analysis is a continuing task in the trade-off process as new designs are considered for inclusion. Experience with reliability and failure mode predictions for the Morgantown command and control system has indicated a good match between predictions and reality when statistical factors such as noise and signal margins could be included in the analysis. The Hagen test track and subsystem testing experience has provided MBB with a measure of potential interference levels and required operating margins. These data have in turn been coupled into design requirements that to date have resulted in operational control system hardware with apparently few noise or signal margin problems. This level can be maintained only by continual appraisal of interface conditions as new modified components are added to the system.

5.5.3.9 TESTING HISTORY

SUMMARY TABLES

CAB Subsystem: Vehicles Component: Cabin (Frame)

	Stage I	Stage II	Stage III
Component Level	Cabin frame BM I/BM II	Cabin frame BM III	
Testing	Fully synthetic plastic construction: insufficient strength of materials (E-modulus GFK* $_2$ = 700 - 1600 Kg/mm^2 Al = 7200 Kg/mm^2 aluminum frame: crash, fire functions, safety tests, wind tunnel trials	Strength and lifetime tests, crash tests (brick-wall crash, vehicle-vehicle crash) fire tests, wind-tunnel testing	
Objective	Proof of strength, fire safety, function, safety and aerodynamics	Testing of improvements with respect to design II reducing the danger of injury for the user	

*GFK = Fiberglass

	Stage I	Stage II	Stage III
Results	For reasons of vehicle strength, further modifications to the aluminum frame, especially stiffening of the edges and corners with cost pieces necessary.	Good lifetime of the design construction; frame resistant to breaking on crash tests, controlled deformation through the crash pad safety front glass prevents severe injury to the passengers; only flame resistant material used; 15% lower weight; good aerodynamics of the GFK front panel.	
Modifications	Preliminary: ropes in the frame Final: Reconstruction for the Model III safety front panel		

	Stage I	Stage II	Stage III
System Level	Two vehicles model I, and five vehicles model II on the test facility at Hagen brought into operation.	Five vehicles BM III, one of which is a 12-place cabin	
Testing	Sufficient number of tests with regard to functional details; long-term test; anthropomorphical tests	Testing on the test facility, functional and long term tests under realistic conditions	
Objectives	Acceptance by passengers Functional utility in practical operation	Proof of maturity of the prototype frame	
Results	The principle of the KK3 passenger cabin was confirmed, however, only with a large number of modifications with regard to technical, anthromorphical and aesthetic considerations	The construction and fabrication principle of the model III frames met expectations. Starting point for a family of vehicles which contained larger vehicles as well (KK12 and Cabinlift models)	

	Stage I	Stage II	Stage III
Modifications	Reconstruction of the frames on the model III vehicles		

Projection Expansion of the vehicle variety for various travel requirements

CAB Subsystem: Vehicle Component: Door

	Stage I	Stage II	Stage III
Component Level	Accordion sliding door BM I	Sliding door BM II	Sliding door BM III
Testing	Installation trials for door mount. Comparative testing.	Functional testing. Stress testing.	Functional testing. Stress testing.
Objective	Selection of a design and/or supplier.	Arriving at a design for a self-closing, hand-actuated sliding door.	Correcting the problems with the BM II door. Determination for improvements.
Result	Two accordion sliding doors were selected in close comparison and each installed in a BM I. vehicle	Construction of a sliding door with roller guides propelled by roller springs equipped with conventional electrical door opening.	The functional problems of BM II door could be corrected. Safe door locking by means of a TÜV tested locker.
Modifications	Large number of modifications to the mechanical design, covering, and operating elements.	Several variations of the spring and roll guide elements were installed.	

CAB Subsystem: Vehicle (Cont'd) Component: Door

	Stage I	Stage II	Stage III
System Testing	Testing of the two-door systems at the EPA in Hagen.	Fitting sliding door on five BM II vehicles (both sides). Testing at the EPA.	Installation of sliding door on the BM II and BM III vehicles. BM III testing at EPA.
Objective	Function and evaluation. under practical conditions.	Testing during trial operations and visiting days.	Functional testing and long term testing.
Result	Unsatisfactory operation. Difficult opening, closing (type 1). Danger of catching fingers or clothing on the edges of the door covering. Improper positioning of the door leaves (sections).	Simplified operation but in part, excessive operating force requirements. Unreliable operation. Roll guides flattened after a short time in operation.	The BM III door system proved to be essentially satisfactory within the definition of a manually operated door. A few tolerance problems with the control unit.

CAB Subsystem: Vehicle (Cont'd) Component: Door

	Stage I	Stage II	Stage III
Modifications	Detail improvements; finally, changeover to straight sliding door design.	Additional center push points for the door sections. Closing damper.	

Projection: Fully automatic sliding doors have been tested on the test bench in Ottobrunn for a long period of time and have been successful in KK3 vehicle at EPA and the Cabinlift at Ziegenhain.

CAB Subsystem: Vehicle Control Component: Headway Measuring Cable

	Stage I	Stage II	Stage III
Component Level		Installation of a signal rail BM II on EPA Function tests and environmental tests.	Refitting the suspended track level with a new measuring cable, continuation of testing.
Tests	Function test together with coupling.		
Objective	Determination of whether or not a headway measurement procedure based on signal attenuation, and a suitable cable were attainable.	Determination of function under environmental conditions.	Correction of problems detected during testing; trials and testing of interaction (among several vehicles).
Result	Sufficient and later good function on the test bench. Difficult mechanical integration and adjusting. Satisfactory fabrication of the cable.	Satisfactory function of holding profile and ferrite reactive connection. Measuring cable absorbed moisture, thus changing its parameters.	Satisfactory to good functioning of entire signal rail.

CAB Subsystem: Vehicle Control (Cont'd) Component: Headway Measuring Cable

	Stage I	Stage II	Stage III
Modifications	Change over to single comb system required a wider cable with a ferrite reactive rail.	Improvement of the contacts between the copper line and carbon brushes. Later redesign of the cable and reactive rail.	Improvement of the mechanical adjustments and contact method.
System Level Testing	Testing of the measuring cable on a circular track in interaction with three vehicles.	Headway space regulation of five BM II vehicles by means of damping measurement system.	Further development and testing of distance regulation along with long-term testing of signal rail.
Objective	Evaluation of long-term usefulness.	Determination of the function of entire system. Endurance testing.	Long-term test during testing of other subsystems.
Results	Satisfactory to good functioning; good endurance under test-bench conditions.	The single comb system satisfactory as a unit; headway measuring cable became unusable due to weathering. Cable covering became wavy.	Satisfactory to good function and very good endurance of the signal rail. Positive results in switching tests.

CAB Subsystem: Vehicle Control (Cont'd) Component: Headway Measuring Cable

	Stage I	Stage II	Stage III
Modifications	Change over to single comb system.	The measuring cable was redesigned with discrete resistors.	Relieving the measuring cable of the excessive accuracy requirements by means of station logic.

Projection: Change over from redundance safety concept to fail-safe monitor. Installation of cable monitor in 1977.

CAB Subsystem: Vehicle Control Components: Headway Measuring System, Transmitter, Receiver

	Stage I	Stage II	Stage III
Component Level	Double comb system.		
Tests	Function tests for coupler by itself and tests of the interaction of the directional coupler and receiver.	Function test of the single comb coupler BM II under laboratory conditions and at the EPA.	Function tests of the BM III coupler, environmental tests and system testing at the test facility.
Objective	Determination as to whether the attenuation measuring system could be realized in principle.	Function determination for the single comb headway measuring system.	Improvement of the function of the mechanics and the reliability. Basis for system tests.
Results	The theoretically expected data for the coupling factor and transmitter efficiency is reached. The receiver created	Coupling factor between the cable and coupler in the limited mechanical tolerance window was sufficiently constant;	Sufficient to satisfactory function; large improvements in reliability, above all little environmental impact.

CAB Subsystem: Vehicle Control Components: Headway Measuring System, Transmitter, Receiver

	Stage I	Stage II	Stage III
	unallowable reflections in the cable.	unallowable cross-talk between the compensator and the receiver; unsatisfactory weather resistance.	
Modifications	The double comb system is difficult to integrate into the initial construction; change over to single comb system.	Various modifications to the couplers; finally redesigning with improved mechanics (BM III).	Improved surface sealing, cable routing, cross-talk damping, Epoxy sealing of electronics.
System Level Testing	Functional tests and trials of the headway measuring system on three vehicles on a circular run with 40 m range.	Fitting the headway measuring system onto five KK3 vehicles; testing at the EPA under severe environmental conditions.	Change of equipment of the BM II vehicle; new construction of five BM III vehicles, among them a 12-seater. Testing at the EPA

CAB Subsystem: Vehicle Control (Cont'd) Components: Headway Measuring System, Transmitter, Receiver

	Stage I	Stage II	Stage III
Objective	Determination as to whether an asynchronous vehicle follower system could be realized by using the parameters distance and velocity.	Determination of function Interrelation with system as a whole. Environmental strength.	Testing of the interval sensors or headway sensors during test with complete longitudinal control system.
Result	Initial realization of the asynchronous vehicle platoon by measurement and regulation of the vehicle interval. Testing all relative operational conditions (stationary and non stationary) successful.	Nearly sufficient function. Satisfactory system compatibility; insufficient coupling tolerance window; insufficient mechanical and maintenance characteristics.	After modification of the measuring cables (see appropriate section). Satisfactory platoon operation, switching operation, and fully automatic test operation. Development target with respect to redundance concepts was realized.

	Stage I	Stage II	Stage III
Modifications	Change over to single comb system; single-sided coupling on the cable with variable gap.	Redesigning in connection with the BM III vehicle.	Additional installation of a safety monitoring system according to the fail-safe principle.

Projection: Testing of the technically improved coupler together with the safety monitoring system in the first quarter of 1978. Fail-safe type safety system monitor is required for compliance with the appropriate German safety specifications.

CAB Subsystem: Network Control Component: Merge Control

	Stage I	Stage II	Stage III
Component Level	Installation of the merging switch at the EPA in Hagen (switch 2a/3); testing of all signal paths.	Modification of switch 2a/3 at the EPA with a new measuring cable and re-worked switch electronics; static testing.	
Objective	Function test of the switch electronics.	Evaluation of the function for the reworked signal path.	
Result	Function of the switch was satisfactory in principle, however, severe problems due to the inhomogeneity of the headway measuring cable.	After correction of a few wiring and installation problems the signal path behaved properly.	
Modifi-cations	Remanufacturing of the new "virtual" headway measur-ing cable; point-to-point adjustment of signals.	Simplification of signal guid-ance in the "hard" imaging area of the switch.	

CAB Subsystem: Network Control (Cont'd) Component: Merge Control

	Stage I	Stage II	Stage III
System Level Testing	Testing of switch with BM II vehicles.	Test and trials of the switch with BM III vehicles.	
Objective	Testing of the signal paths from vehicle to vehicle. Testing of switch logic. Dynamic switch tests.	Static and dynamic function test under all attainable situations; long-term testing of the signal paths.	
Result	Satisfactory function of the merge control unit; and unsatisfactory test runs due to measurement cable problems; guideway electronics susceptible to failures.	Good functioning of the total system, switches and vehicles. Successful long-term test with minimal failure rate.	

	Stage I	Stage II	Stage III
Modification	Reworking of switch in connection with new measuring cables.	Modification of the switching control electronics to prevent mutual blocking of vehicles in an extreme circumstance.	

Projection: Further simplification of control electronic areas with concurrent improvement of safety in development. Work towards fail-safe monitoring of the signal paths.

CAB Subsystem: Vehicle Control Component: Data Transfer Link

	Stage I	Stage II	Stage III
Component Level			
Tests	Function test, Temperature test, EMV-test, Bit error test.	Function test, Environment test EMV-test under severe conditions.	
Objective	Determination of function alone and with headway measuring system.	Correction of problems found during testing.	
Result	Satisfactory function under laboratory conditions; poor maintainability.	Problem-free function of the high frequency link, interference problems in the audio frequency sections. Improved maintainability through the installation into electronics box.	

CAB Subsystem: Vehicle Control (Cont'd) Component; Data Transfer Link

	Stage I	Stage II	Stage III
Modifications		Modification of the evaluation circuit, there-after the problem was corrected.	
System Level Testing	Installation into five BM II vehicles; testing at the EPA in connection with on-board equipment.	Installation of the BM III electronics in 10 vehicles, testing of entire system with station control.	
Objective	Determination of total system function.	Extended period testing.	
Result	Strong interference from impulse noise; unsatisfactory mechanics (see headway measuring system).	Problem-free interaction with station control; audio frequency stage (beacon) were made interference-secure through modification.	

CAB Subsystem: Vehicle Control (Cont'd) Component: Data Transfer Link

	Stage I	Stage II	Stage III
Modifications	Reworking of the circuits for the BM III electronics. Removing interference from a few on-board components.	Filter in audio frequency stage; no other modifications necessary.	

Projection: Acceptance of the components essentially unmodified for the Bremen project.

	Stage I	Stage II	Stage III
Component Level Test Objective	As pages 5-58 to 5-60	As pages 5-58 to 5-60	
Results Modification	As pages 5-58 to 5-60, however, better access was accomplished by the installation of water-tight cast housing for mounting of the system on the guideway.		
System Level Testing	Equipping of station 01 and the switch with data transfer points. Testing with the vehicles.	Equipping station 01 and 02, as well as the switches with data transfer equipment BM III; testing.	

	Stage I	Stage II	Stage III
Objective	Determination of total system function.	Long-term testing.	
Result	As pages 5-58 to 5-60, additionally, unsatisfactory maintenance because of the fact that electronics were installed on guideway.	Problem-free interaction with the vehicles; simplified maintenance.	

Projection: None

	Stage I	Stage II	Stage III
Component Level			
Tests	Functional test of hardware and software with simulated peripherals.	Function test with original peripherals from BM III vehicle and BM II machines.	
Objective	Determination of function and correction of problems (software).	Correction of problems found during testing; test of BM III vehicle electronics.	
Result	Satisfactory function under laboratory conditions; however, suseptibility to interference when using PDP 11/15 computer.	Problem-free function under laboratory conditions as well as at the EPA.	
Modifications	Modification of the station computer interface (data multiplexer).		

CAB Subsystem: Network Control (Cont'd) Component: Station Control Unit

	Stage I	Stage II	Stage III
System Level Testing	Equipping of station 01 of the EPA with complete station control BM I.	Fitting of station 01 and 02 of the EPA with station control BM II.	
Objective	Function test and trials with BM II vehicles.	Testing with BM III vehicles in automatic test operation.	
Result	No significant functional problems, however, decreased reliability of the station computer because of increased environmental temperature (direct sunlight).	Problem-free function and the smallest possible failure rate; a large number of modifications to the software from testing trial and demonstrative operation.	

	Stage I	Stage II	Stage III
Modification	Installation of air conditioning; new designing of BM II with different type of station computer.	Expansion of the possibilities for testing. Preparation of network computer cable connections.	

Projections: Testing of the relationship between Network computer and station in second quarter of 1977.

In future projects: Use of a micro-computer for station control units.

CAB Subsystem: Network Control Component: Travel Ticket Machines

	Stage I	Stage II	Stage III
Component Level	BM I	BM II	
Testing	Function test in relationship to station control.	Function test with station control unit BM II.	
Objective	Determination of function for magnetic card terminal, operation elements, electronics.	Determination of function. Testing of the appropriate computer software for station computer.	
Results	After correction of development errors, satisfactory function under laboratory conditions.	Problem-free function under laboratory condition.	

CAB   Subsystem: Network Control (Cont'd)   Component: Ticket Machines

	Stage I	Stage II	Stage III
System Level Testing	Equipping of station 01 with one station automat and four platform automats; testing with BM II-vehicles.	Equipping of station 01 and 02 with ticket machines; testing with vehicles and passengers.	
Objective	Function and evaluation of acceptance by the public.	Improvement with regard to BM II; Long-term test.	
Result	Satisfactory technical function. Electronics and operation elements, however, were susceptible to failures. Deficiency in protection from weather elements. Operation can be simplified.	Problem-free function when installed according to specification; Simplified facilities for the Cabinlift requires simplified operational equipment.	

CAB Subsystem: Network Control (Cont'd) Component: Ticket Machines

	Stage I	Stage II	Stage III
Modification	Modification of the operation in consideration of the weak points of the BM II.	Modifying of station 02 to the push-button operation (lift control).	

Projection: Future ticket machines should be autonomous to a large extent; Use of a micro processor at least in the station automat. In this respect experience gained in the "RETAX" (DIAL-A-BUS) project could be of help.

6. HUMAN INTERFACES, SAFETY AND SECURITY

6.1 INTRODUCTION

During the period from summer of 1974 to fall 1975, the Technische Überwachungs verein e.V (TÜV) conducted and reported a study entitled "Ergonomic and Safety Technology Demands on New Types of Short-Distance Transit Systems," [20]. This publication, commissioned by the Federal Ministry of Research and Technology of the Federal Republic of Germany, is reportedly under revision. Unfortunately a translation of the report was not available prior to the on-site system review, and there was no opportunity to consult with TÜV during the October 1976 visit to Germany. The assessment conducted by TÜV of the human interfaces, safety and security with respect to the Cabintaxi Systems was very detailed. Thus the TÜV report is recommended to any one desiring particularly detailed information on and evaluation of the human engineering specifications such as the physical dimensions of the stations, levels of illumination at all user-system interfaces, the quality of the instructions (in German for the German public) for the fare collection and use of the system, as well as other factors affecting the ease of the use of the system.

The data presented in the TÜV report was at least a year old at the time of the review and it is reasonable to assume that many of the recommendations had already been incorporated into the Cabintaxi System in the interim or will be as new models are designed and built. The latter applies particularly to such major construction projects as stations, since retrofitting or rebuilding of these structures at the Hagen Test Facilities is certainly not warranted. Furthermore, some of the human engineering specifications are culturally related. Differences in the cultures of the U.S.A. and Germany dictate differences in design. The current fare collection system used in Germany is a case in point; a barrierless honor system for fare collection would probably not be respected by the typical transit passenger in the U.S.A. In addition, any system built within the U.S.A. will be subject to differing local building and fire codes.

6.2 OPERATION/MAINTENANCE INTERFACES

Operation/maintenance interfaces are still at the concept stage. The operational system at the Hagen Test Facility is designed for test purposes and simulated revenue operation.

Some thought has been given to design of the central control operator's facility, since one will be needed for the Bremen System. It was suggested that the most likely approach to this problem will be to use equipment similar to that used in the display system for the simulations being employed in the network design studies (Section 4.12/4.13).

Maintenance of the system should be facilitated by the approach expressed at MBB to "automate to the greatest possible degree". The system should strive for self-checking both for the status of the equipment and the status of operation. The operators and controllers are expected to be alerted to any disturbance by the automatic system itself. It is recognized that with such a system the operators and controllers must undergo periodic training in order to be able to take over the system in the event of a major system failure such as the main computer. Under such circumstances, the best that can be hoped for is for the system to fail gracefully. With such an occurrence, user complaints will be a major problem.

The philosophy relative to control and maintenance information is that each vehicle will maintain its own log. Limited vehicle operating information will be transmitted to central control, and, if critical, would cause emergency braking utilizing the vehicle's spring loaded brakes. Under this condition, the vehicle would have to be retrieved. Lesser failures would cause the vehicle to go into a normal service braking condition from which it would also have to be retrieved. The third lower level of failure would program the vehicle to the nearest station at which the passengers would be evacuated. A voice link may also exist between central control and the various vehicles and stations.

At Ziegenhain maintenance is effectively done on-line. With a system such as that proposed for Bremen, full maintenance facilities will be required. Various possible designs for maintenance facilities are being considered.

At the present time no actual maintenance manuals exist except a single one compiled for the system at Ziegenhain, which is a compilation of notes peculiar to that particular system. Since the system at Ziegenhain is unique

and no other CAB "system" is yet deployed except on the test track, maintenance manuals in the true sense of the term are not yet necessary.

Contracts have been negotiated with existing transportation systems to obtain estimates of maintenance personnel requirements as well as the relia-ability of various common components. Maintenance costs for personnel and materials are currently estimated as described in sections 7.5.1 and 7.5.3. These maintenance costs are based on the level of quality assurance used by MBB and such organizations as Lufthansa. To maintain the necessary availability during peak demand periods, the number of extra vehicles (percent of the fleet) is estimated.

Planning for the city of Marl, (estimated via simulation 1600 vehicles) anticipates requirements for about 200 operation, maintenance, repair, and support personnel. These estimates are based on a mathematical model utilizing data obtained from many sources such as Federal Rail, the German U-Bahns, MBB's own industrial requirements, and Lufthansa Airlines.

6.3 NOISE ASSESSMENT

6.3.1 Exterior Noise

An extensive program has been undertaken to make the noise emitted by the Cabintaxi Systems the lowest of all transportation systems. Noise tests have been made at the Hagen Test Facility by K. P. Schmidt, Mettman.

Evaluation of noise emission from the Cabintaxi was carried out from different positions, at long and short range, at different speeds, on both suspended and supported tracks.

Results reported to date are as follows:

1) The Cabintaxi, at a speed of 10 m/s = 36 km/h at a mean distance of 7.5 m from the center of the tracks, had an average noise level of 62 dB(A) for the elevated track (suspended car) and 65 dB(A) for the standard track measured on a closed loop course.

2) There are occasional short bursts of noise which exceed the mean level by more than 10 dB(A). These bursts are not considered significant, since measures taken in construction will allow them to be avoided.

3) Over single sections of the track (for example, curve 12/13 for the suspended track at a speed of 10 m/s) at a distance of 7.5 m a noise level of 58 dB(A) has been attained.

4) For the cabintaxi suspended track with the following parameters:

Speed	10 m/s = 36 km/h
Measurement distance	7.5 m from track middle
Traffic density	1000 vehicles/h

the average value over all track sections on the guideway, evaluated with reference to the VDI guideline 2516 (Noise Conditions on Metropolitan Railways), showed an equivalent continuous noise level of 60 dB(A).

5) For a traffic density of 20 vehicles/hour (night time) under the same conditions as in 4 above, the Cabintaxi achieved an equivalent continuous noise level of 43 dB(A).

6.3.2 Interior Noise

No data on interior noise of the Cabintaxi Systems were available at the time of the review.

6.3.3 Assessment of Noise Levels

The exterior noise levels of the Cabintaxi Systems as judged from direct observation were very low, so low that concern was expressed that care must be taken when crossing under the guideway to ensure that no vehicle was approaching. The noise levels observed could in no way be considered offensive. These observations are supported by noise level readings of between 60 and 65 dB(A).

Although no objective measures of noise levels for the interior of the vehicles were available, no difficulties were experienced carrying on conversation while traveling in a Cabintaxi vehicle at a velocity of 10m/sec.

6.4 RIDE QUALITY ASSESSMENT

The normal operational acceleration and deceleration of all the vehicles were very smooth with no apparent jerk. No measures of the physical attributes of the ride quality were available at the time of the assessment. It was recommended that the ride quality/comfort be measured in terms of the RMS amplitudes of the accelerations for each of the six degrees of freedom for the bandwidth 0.1 - 10 Hz as well as according to the procedures given in Section 4.2 of the International Standard, ISO 2631.

6.5 FARE COLLECTION SYSTEM

6.5.1 Honor System

The fare collection system in use for the Cabintaxi/Cabinlift systems at tne Hagen test track does not employ barriers. In this respect it resembles the "honor system" of fare collection used by the Hamburg and Munich U-Bahns and S-Bahns. There are no fare collectors, turnstiles, or other barriers to ensure the payment of fares, merely automatic ticket dispensers and ticket concellation machines.

In the case of the U-Bahns, and S-Bahns, there are periodic checks of all passengers for payment of fares. If one is found without the appropriately cancelled ticket or pass, the fine can be as much as DM20, about $8. Fares can be paid either by the purchase of a pass good for a specific period of time on a specific portion of the transportation system, or purchase of single and multiple trip-tickets from vending machines. The trip-ticket must be inserted into a ticket-cancelling machine, if one does not want to risk the payment of a fine for fare evasion. The cancelling machine stamps the ticket wit the place, date, and time. Normally, the only transit personnel in the stations are information clerks who are not responsible for checking fare collection. Except for spot checks (random sample controls) on the "honor system", there are no transit personnel in the stations or on the trains to ensure that all passengers have paid the appropriate fare.

There has been little or no experience in the U.S.A. with barrierless public transportation systems. Such a system for the collection of fares might be appropriate for a personal, demand-type, magnetic-card-controlled system in

which the fare is paid for the use of the vehicle, rather than for the seat (e.g. KK3 systems). In these systems, the vehicle would probably require an overload interlock. However, a fixed route or mixed mode system with large cabins (e.g. KK12 or Cabinlift) would probably require some form of barrier in the United States, since it is estimated that even with the most stringent methods of ensuring that the passengers pay their fares, there are still thousands each day who do not. The annual loss in revenue due to fare evasion has been estimated in the past to run as high as $15 million a year. The use of magnetic ticket systems with or without barriers would also allow origin-destination and other information on the passengers to be collected automatically. This data could be extremely valuable in refining such aspects of the system as schedules and empty vehicle management.

It should be noted, however, that there are applications for AGT systems which do not require fare collection from the passengers, such as at fairgrounds, factories, hospitals, and some airports.

6.6 ASSESSMENT OF PUBLIC ACCEPTANCE

The problem of evaluating public acceptance and the potential market for Cabintaxi Systems as public transportation were pursued during this review. The conclusions drawn were that a definitive study has still to be done on the public's response to Automated Guideway Transit Systems in general and Cabintaxi in particular. The methods used to date have resulted in the study of the public's relative acceptance of, preferences for, and attitudes towards various attributes of transportation systems' safety, aesthetics, punctuality, comfort, and availability. These studies do not determine sufficiently the strengths of these preferences and attitudes so that the future acceptance of, and demand for various modes of transportation can be predicted with any degree of confidence.

The study on public acceptance of the Cabintaxi as a form of transportation as reported by TÜV showed very positive results. Apparently due to the narrowness of the guideway and a resulting feeling of instability during the ride, the suspended system was slightly preferred to the supported.

The other aspect of the problem of public acceptance is the mere presence of the system. The supporting columns are quite thin and, in and of themselves, are acceptable; however, the presence of such a column outside one's door or window can be another matter. It is understood that the reason for the pylon suspension of the guideway at one point for the Cabinlift at Ziegenhain is due to the objection of having a supporting column immediately in front of a window. Public acceptance of the intrusion of such elevated systems as the Cabintaxi Systems is a pressing problem facing the deployment of these systems in truly public areas.

6.7 USER-VEHICLE INTERFACES

6.7.1 Vehicle Doors

Since the Cabintaxi Systems operate on an elevated guideway, passengers would be greatly endangered by an inadvertent door-openning. At the Hagen Test Facility, the door of the vehicle can be opened only after the vehicle has come to rest in the station. After the passenger has paid the fare and selected his destination, the door of the vehicle closes and locks automatically before the vehicle is able to move from the station platform. Once the vehicle is under way, the passenger has no way of opening the door until the vehicle has arrived and stopped at a station. The use of a key is necessary to access a vehicle from the outside unless it is appropriately berthed in a station.

6.7.2 Assessment of Door Operation

The interlock system that prevents the doors from being opened by passengers except when berthed properly in a station coupled with the security of the structure of the door assembly as shown by the crashworthiness tests should prevent any inadvertent door opennings. It is imperative, however, with such a system for operating the doors, that the probability of a fire which would halt a vehicle between stations is at an absolute minimum.

6.7.3 Heating, Ventilation, and Air Conditioning

The heaters used in the three-passenger CAB vehicle consume a maximum of 3000 watts. Plans call for two such heaters for the larger vehicles, e.g. those to be used in the Bremen System. These heaters are considered to be

sufficient for thermostatic control of the temperature in the vehicles at 20-22 degrees Celsius in cold weather. The heating, ventilation and air conditioning requirements, in the U.S.A. are much more demanding than those in Germany. Ambient temperatures in many regions of the U.S.A. can range between as much as -35 and 50 degrees Celsius. Correspondingly transit systems should maintain interior temperatures of their vehicles between 13 and 26 degrees Celsius.

Special precautions have been taken with the present Cabintaxi vehicles to protect the passengers from the heating elements of the electric heaters. The heaters are constructed so that objects inserted through the grillwork of the heater cannot contact the heating elements.

Cooling of the vehicles in warm weather depends entirely on the flow of air in and out of the vehicle through a system of ventilators.

6.7.4 Assessment of Heating, Ventilation and Air Conditioning

The wide variations in temperatures experienced across the U.S.A. would suggest that the "flow through" ventilating and cooling system adopted for the Cabintaxi System would prove inadequate for the U.S.A. market, i.e., air conditioning would be required. Inasmuch as passengers in a Cabintaxi vehicle are virtual prisoners if the vehicle is stalled between stations, it is imperative that the vehicle have some form of ventilation and/or air conditioning which will still maintain it at reasonable temperatures. Experience with existing systems in the U.S.A. has indicated that without air conditioning, a stopped vehicle becomes intolerable to passengers after about five minutes.

6.8 SAFETY

6.8.1 Fire Safety

The manufacturers have written fire regulations for the Cabintaxi/Cabinlift system based on those of the aircraft industry and applied them to the appropriate aspects of construction. The TÜV (Technical Safety Administration responsible for transport safety) has reportedly judged these regulations as sufficient, with the exception of a few suggestions for modification.

An important element of the fire safety considerations was the separation of the high power propulsion drive components of the propulsion controller from the low power safety-related control electronics. In addition, vehicle

sense and transmitting antennas for control of velocity, vehicle separation distance, switching, etc. are positioned such that they would be unaffected should the fire occur in the propulsion controller. A heat shield is also planned between the propulsion controller and the cabin to reduce the possibility of a fire in the controller from spreading into the cabin.

It is planned (and partly realized) that high power carrying cables between the logic and propulsion controller be armored againt mechanical damage. Short circuit protection is provided by circuit breakers. Thermal protection devices in the bogie will stop the vehicle should overheating occur. In this case, a recovery vehicle would be necessary when automatic pushing from a following vehicle could not be carried out.

If in spite of all precautions fire or smoldering does develop in the bogie of the vehicle, smoke could enter the cabin through air openings, expecially when the vehicle is stopped. On the newer vehicles ducting similar to that used by the aircraft industry has been installed.

The principal precautions against fire are that the interior heating unit is electrically insulated and inaccessible to the passengers and flame retardant materials are used throughout the vehicle. The material used is tested by the manufacturer with regard to its fire safety, and a certificate is provided. Flame retardants of self extinguishing synthetics (e.g. for seats) could, smolder however, generally creating heavy smoke. A smoldering, charring fire in the cabin need not lead to an insurmountable choking or gas poisioning problem. One possible solution is to have smoke and gas removed by high capacity forced ventilation or by manually operated ventilating doors in the car, alleviating the effects of gas and smoke on the passengers. This system would necessarily be operative when the vehicle was stopped.

The danger of fire from the ignition of materials foreign to the system also exists. As an example, a passenger who smokes may ignite a newspaper, endangering the other passengers. The cars could be equipped with hand-held fire extinguishers. Smoking in cabins which are carrying inflammable materials should be prohibited. Ash trays and trash receptacles should be located at the train entrance corridors in the stations, so the passengers may use them shortly before boarding.

The possibility of set fires or vandalism can not be disregarded or completely prevented. In 1976, for example, an unoccupied car of the Hamburg Elevated Rail AG was burned when youths poured gasoline in the car and ignited it.

An intercom system can be installed in the car so that the passenger can press an emergency button if a fire is noticed and contact central control (switchboard). The car would continue to the next station where the doors may be opened. Except for use of the rescue vehicle, the doors could only be opened to allow escape between stations if an escape platform is installed along the entire length of the line trestle. In the manufacturers' view, this involves additional costs and would detract from the aesthetics of the system. Therefore, a relatively short transit time between stations was considered instead. In most planning studies to date, the distance between stations is from 400 to 700 meters. The stations should be equipped with fire extinguishers for fighting fires, which are well secured to prevent theft.

It is expected that fire testing on completed vehicles will be carried out by the manufacturer to gather further information regarding the development of smoke toxicity and ignition temperatures.

6.8.2. Crashworthiness

In automated guideway transit systems, sophisticated headway assurance subsystems are designed for collision avoidance and are the primary mechanisms for system safety. The redundancy design concept incorporated in the control elements of the headway measuring system makes a large contribution to the safety of the Cabintaxi system. The theoretical probability of a failure in the active safety equipment according to the manufacturer lies on the order of $4 \times 10^{-14} \times h^{-1}$ to $13 \times 10^{-10} \times h^{-1}$. Even in the event of a safety system failure, a crash situation does not necessarily exist since two vehicles may not be in proximity to each other. Thus, the chances for a collision due to failure of the collision avoidance system can be considered as "vanishingly small". In spite of the goal of a fail-safe headway assurance system, crash testing was carried out for the KK3 type vehicles (3 seated passengers, no standees). The following types of impacts have been investigated.

- into a stationary solid object (brick wall crash)
- into a stationary vehicle (vehicle-vehicle crash)

The crashworthiness tests of the vehicles of the Cabintaxi systems are being carried out for DEMAG and MBB by Allianz, Zentrum für Technik and by the University of Technology, Berlin testing centers, which do testing work for both government and industry.

The criteria established for the crashworthiness of the Cabintaxi system vehicles travelling at 10 m/s are that:

- the passenger cabin retains its original form and integrity,
- the cabin suspension system remains completely functional,
- the doors must remain closed and operable,
- the cabin's interior furnishings do not break loose from their retainers,
- no large pieces break loose from the cabin (presenting danger to the surrounding area), and
- in case of cabin deformation, no parts breach the passenger cabin walls.

These criteria for the vehicle have been met in the crashworthiness testing program.

In addition, passenger personal injury criteria were also investigated for the head, chest, thigh, and cervical vertebrae utilizing four different safety systems:

- 3-point automatic safety belts and head rests
- air bags of various designs
- crash pad plus safety glass in front (of different lamination designs)
- backward seats (seats facing away from the direction of travel).

In these tests, the manufacturer reports that no lethal danger was presented to the passengers, although with the crash pad plus safety glass

system, a few experimental parameters reached critical values for the passengers. The manufacturers feel that substantial improvement of all parameters is easily attainable through precise workmanship and continuing research and optimization of the safety features.

6.8.2.1 Brickwall Crash

The collision of a vehicle with a stationary solid object during daily operation is most unlikely. In spite of this, however, safety features of the vehicle were investigated by the manufacturer for this condition. In addition to equipment for the complete protection of the passengers from injury, the effect of a deforming (energy absorbing) front section was tested.

By conducting tests using anthropomorphic dummies, it has been determined that either appropriately designed seat belts or air bags will offer passengers full crash protection. However, the opinion was expressed that a seat belt system is very likely to be unacceptable or too complex to be usable by a large proportion of the passengers, and a properly designed airbag system is inordinately expensive. Since neither of these systems are deemed practically effective, other methods were considered to protect passengers.

The basic proposed method of protecting the passenger in the event of a crash is to turn the entire inner front end of the vehicle into a crash pad together with utilization of a windshield made out of multiple layers of glass and plastic which will stretch on impact. To prevent lacerations from the glass, the inner surface consists of a layer of plastic. This could present a surface for potential attack by vandals and also be difficult to clean.

New glasses for the windscreen, Triplex Glass No. 1020 and Securit Securiflex III, are under consideration. With the plastic laminated windscreen, nonlethal levels of deceleration with respect to head injuries have in part been reached.

For the torso and legs the most successful approach has been to install a crash pad below the windscreen on the front wall of the vehicle. Three types of crash pads have been tried. One was a light metal "honey comb" similar to that of an automobile radiator, and the second a synthetic foam crash pad. Neither of these approaches was found to be as effective as a bulge of light

sheet metal which will dent and crush on impact.

The test results with the light sheet metal crash pad in combination with the special windshield have led to "non-lethal" injuries being sustained by the dummies in most crash situations. According to the manufacturers, continued testing should allow optimization of the safety features so that a lethal situation could not arise under experimentally foreseeable conditions.

6.8.2.2 Vehicle-Vehicle Crash

On the vehicle-vehicle collision the undercarriage of the cabintaxi vehicle will absorb the impact with a deceleration of about 30 g when the collision occurs between a stopped vehicle and one with a velocity of 10 m/s (current maximum velocity). Tests showed that the danger of injury to the head and chest is larger in the stationary cabin than in the moving cabin.

No lethal danger was presented to cabin passengers in any tests involving collision between two cabins. An oblique collision between two vehicles during switching operations was not investigated, although the result of an accident during another set of tests on the test track in Hagen may be informative in this respect.

At a speed of about 7 m/s with the headway measuring system disabled, the pilot of the moving cabin suffered only a laceration wound in the leg from a piece of measuring equipment which was standing on the floor. His head struck the windscreen (windshield) but he suffered no facial injuries.

6.8.2.3 Reverse Seating

Another possibility for protecting passengers in the event of a collision is to reverse the seating in the vehicle so that all passengers face away from the direction of motion. Reverse seating may offer much more protection in the event of a brickwall stop.

The public apparently no longer expects to ride seated facing in the direction of travel, as indicated by the seating arrangement in many modern transit vehicles, and reverse seating has been standard for decades for half the seats in European rail vehicles. Reverse seating, especially if the

window arrangement were similar to that found in a Brougham type vehicle, may well decrease the sensation of instability that one can have while riding facing forward in a supported cabintaxi vehicle. (This feeling of instability at speeds of only 10 m/s is probably due to the narrowness of the guideway and may affect the desirability of higher speeds.) The elimination of the immediate lateral field of view would not only reduce the apparent speed of the vehicle by reducing the perceived motion parallax but would also prevent passengers in the vehicle from looking directly into the windows of buildings adjacent to the guideway unless they made a special effort to do so. Any reduction in the intrusiveness of such a transit system as the Cabintaxi might well increase the public acceptance of such elevated systems.

Reverse seating could also help to reduce the potential of bodily injuries to passengers in the event of an emergency stop. Tests of deceleration levels for emergency stops have been conducted with the Cabintaxi systems with passengers seated facing in the direction of motion. These tests have shown that passengers remained in their seats when the vehicle stopped with a deceleration of 6-8 m/s^2.

The emergency braking rate is on the order of 5-6 m/s^2. However, two members of the assessment team were very nearly spilled from their seats while in a cab vehicle at the Hagen test facility when the vehicle made a false positive emergency stop. Such aids as foot rests and seat contours, covering and softness are being investigated in order to help passengers retain their seats in the event of an emergency stop. This is a question of design, in consideration of providing room for a baby carriage, wheelchair, or luggage, etc., in the vehicle.

6.8.2.4 Crashworthiness Assessment

The standard approaches to the problem of crashworthiness, airbags, seat belts and crash pads have all been investigated. The goal is, within the framework of a safe yet economical vehicle, to have the highest measure of security from passive type safety equipment.

Alternatives were sought to replace airbags and seat belts due to difficulties with use and cost. In principle, however, the Cabintaxi could be fitted with these systems. Development of the crash pad was especially pur-

sued. The crash pad in connection with windshields, at the time of these tests, had reached the point where even the effects of a very unlikely event, that of collision with a solid stationary object after failure of the headway holding system, were greatly reduced.

On the basis of tests conducted up until now, the manufacturers feel that through further developmental work, real chances exist that a passenger compartment can be achieved in which:

- in the exceptional case of a brickwall crash, the impact energy will be greatly reduced and
- the construction and interior compartments can be so designed that passengers would suffer no lethal injuries.

Thus, the Cabintaxi exhibits good characteristics with regard to its crashworthiness.

6.9 SECURITY

6.9.1 Vandalism and Personal Security

The interior of the vehicles has been made as vandal-proof as possible. For example, all screws inside the vehicle are a tamper-proof type which for the most part are not visible, and the overall construction is such that there are no ledges for one to climb on.

The philosophy to be applied to deterring vandalism is to educate the public and/or users to the fact that the transportation system is their system, and that they have paid for it. If they vandalize it, they are destroying their own property. The windows of the vehicles have been designed to be as large as possible, making the interior of the vehicle very public in order to further deter vandalism and acts of crime in the vehicle. TV monitoring is being considered, but for a system with a large number of stations and vehicles, TV monitoring becomes expensive assuming each station is to be surveyed for more than a few seconds each hour. Security, per se, is not considered a major problem in Germany. It is recognized that poorly maintained stations and vehicles breed vandalism. As a result, the stations and vehicles must be constructed for easy cleaning. The vehicles have been designed to

be washed on the outside with high pressure spray and then blown dry with air.

6.9.2 Assessment of Vandalism and Personal Security

Most vandalism occurs following such events as sporting events, and in the U.S.A., following rock concerts. Automated Guideway Transit vehicles and stations will be particularly susceptible to vandalism at such times unless particular steps are taken to prevent it.

Station elevators built as a cage lined with heavy glass or plastic and brightly lighted could well inhibit unpleasant behavior which is experienced both in Germany and in the U.S. in public transportation systems, such as indiscriminate urination.

Considering the level of crimes such as pickpocketing and of vandalism on manned mass transit systems in the U.S.A., the passengers and equipment of Automated Guideway Transit Systems, having unmanned stations and vehicles, are particularly susceptible to these asocial types of behavior. Every known deterrent will have to be employed to keep vandalism and crime to a minimum on automated systems in truly public areas.

Although "mugging" is a general problem, the inability of a passenger to stop or leave a vehicle between stations in the Cabintaxi system makes him particularly defenseless.

6.10 TRANSPORTATION OF THE HANDICAPPED AND ELDERLY*

Since the handicapped and elderly are especially dependent on public accommodations, every effort should be made to afford such people the opportunity for independence of travel.

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*A discussion of general requirements for the transportation handicapped can be found in "Findings and Conclusions."

The social importance of this population group is given by the following figures:

Data in 10^6	U.S.A. 1970[1]	U.S.A. 1975[3]	West Germany (DBR) 1966[2]	West Germany (DBR) 1975[4]
Total population	204,9	213,6	59,1	62,0
Population over 65	20,0	22,0	7,4	8,9
Handicapped over 65	7,0		1,7	
Handicapped under 65	6,4		2,3	
Handicapped in wheel-chairs	0.4			

This indicates that about 7% of the total population of the U.S.A., as well as West Germany, are handicapped in some way. Of those in the U.S.A., about 3.2% are confined to a wheelchair. Since in Germany about 16.4% (12.9% in the U.S.A.) belong to the handicapped or elderly group which rely to a large extent on public transport, special requirements should be established for public transport systems. Special individual or public transport facilities must be established only in a limited number of cases.

The accommodations of the Cabintaxi/lift systems for transportation of the handicapped are discussed below. However, little consideration for the various accommodations was taken at the facility in Hagen, since there was no necessity for such provisions in the test environment.

6.10.1 Cabintaxi KK3 and KK12 Vehicles

These two vehicle types are similar with respect to their use by the handicapped. The width of the door opening is 68 cm. A wheelchair can gain access; however, due to the vertical distance between the platform and the vehicle, assistance may be required. In order to provide comfortable entry for persons confined to wheelchairs, a door width of 80 cm is recommended.

To facilitate exit, a rotatable hand grip provided by the manufacturer is planned. After use, this hand grip will automatically return to its position underneath the ceiling, so as not to present an obstacle.

The interior space of the cabin is so arranged that in the 3-seat cabin, aside from a wheelchair and its occupant, there is room for an attendant. In the larger 2 compartment, 12-seat vehicle, the number of seating spaces would be reduced to 4 per compartment when accomodating wheelchairs.

The vehicle's floor and the station platform have a height difference of about 15 cm when empty; therefore, a person in a wheel chair may require assistance to negotiate this difference (see Fig. 6-1). Larger stations (those with several berths), should be designed to have a boarding point with no height differences between car and platform. This could be accomplished, for example, through the use of ramps. The manufacturer offers a car lowering accessory, available at extra cost.

All stations above ground or under ground should be equipped with elevators. Ground level stations should provide ramps for entry and exit.

Figure 6-1. Vehicle Floor and Station Platform Height Difference

6.10.2 Cabinlifts

At the present time Cabinlift systems, with the exception of the special Cabinlift system at the Ziegenhain Hospital, are in the planning phase. Lift systems planned for hospital premises (for example, the Central Hospital in Bremen) would have similar accommodations to those of the Ziegenhain Cabinlift system with regard to use by the handicapped. (See Appendix A),

Integration of the stations is planned so that they can be accessible by way of the building elevators. Access corridors are sealed off with automatic doors which open at the same time as the vehicle doors.

The width of the door opening for all Cabinlifts projected to date, as well as for the existing system in the Ziegenhain Hospital, is wider than 80 cm.

The gap between the vehicle floor and the station platform is kept very small by use of mechanical apparatus (for the transport of beds on rollers).

Seating is planned on the front and side walls of the car. It is desirable that all vehicles be equipped with well placed hand grips and hand rails.

7. SYSTEM COSTS

7.1 INTRODUCTION

It is difficult to quote costs for the Cabintaxi/Cabinlift system. Aside from one special application of the Cabinlift system at the hospital in Ziegenhain (see Appendix A, Section A.6), and the test facility in Hagen, none of these systems have been installed and put into passenger carrying operations. There exists, however, detailed plans (either completed or will be completed shortly [4,26]) for the deployment of these systems for several cities in the Federal Republic of Germany. In addition, there are data available from a wide range of technical test runs and simulation studies.

Since the system cost depends to a very large measure on the conditions and the actual areas in which the system is to be utilized, it is necessary that the following guidelines be adopted:

- The system could be built in its typical standard design under normal constructional requirements and conditions (that is, without special structural difficulties). Consideration will only be given to track sections elevated above the streets. (No tunnels and ground-level tracks).
- Capital costs apply only to a system which is in full operation. The effects of extending the network and phasing the operation over several years will not be considered.
- Special cost requirements that are application-specific will not be considered. Examples include:
  - Specific financing schemes
  - Ground acquisition and damages, secondary building costs, tax and insurance, savings or additional costs due to already available public transport systems and their facilities.
  - The effects of private or semigovernmental bottle necks which would prevent the quick and efficient construction of the system.
  - Legal and individual damage inquiries

- A network of average size be used to calibrate the price per unit, or in this case, the capital costs per kilometer. The characteristics of this average size network are:

  KK3: 50 km of track length

  double level guideway only, off-line stations

  KK12:60 km of track length

  double level guideway, off-line or on-line stations

  suspended rail, has off-line or on-line stations

  top-mounted rail, has off-line or on-line stations

  Cabinlift: 2.4 km track length (one direction traffic)

  suspended rail, only on-line stations

Based on the guidelines given above, Section 7.2 lists the cost of the subsystems of the Cabintaxi/Cabinlift system. Fiscal considerations and the investment cost per kilometer are given in Sections 7.3 and 7.4. Section 7.5 gives an estimate of the operational cost, also in terms of per kilometer. The last section gives the total system costs based on deployment studies in Marl and Munich. The cost information is based on experience which has been gained from having actually fabricated the components, or in some cases, from data worked out by the manufacturers.

7.2 SUBSYSTEM COST

7.2.1 Guideways

The guideways consist of the following components:

- Guideway beam with its equipment
- Supports
- Switches with their equipment

Table 7.1 lists the unit prices for the Cabintaxi system KK3 and KK12.

7.2.2 Central Control and Checkout

To a large extent, the system is free from personnel in its operation. The capital requirements for the equipment providing most of the automation (central computer, station computers, switch mechanisms, and checkout) do not differ substantially from system to system. Table 7-2 gives the cost for the

Table 7-1

PRICES FOR GUIDEWAY COMPONENTS (AVERAGE SIZE NETWORK)
CABINTAXI KK3 AND KK12

Component (completely functional)	Unit	Price per Unit (thousands of DM, TDM)
Guideway Beams	km	
- straight		
double		5,000.--
suspended		3,500.--
top-mounted		3,500.--
- curved		
double track		5,900.--
suspended		4,200.--
top-mounted		4,200.--
Supports/Foundations	Piece	
- Double track		
(cantilever arm)		40.--
(T-support)		50.--
- Suspended track		
(cantilever arm)		35.--
- Top-mounted track		
(mushroom support)		25.--
Switch Mechanism	Piece	
- Double track		350.--
- Suspended/top-mounted		260.--

central computer facility and the checkout equipment per vehicle. The costs for the vehicle control and switch mechanism are contained in the figures given for the vehicle and the switch, respectively. Station computer will be considered as part of the station cost.

Table 7-2

PRICES FOR CENTRAL CONTROL AND CHECKOUT
(AVERAGE SIZE NETWORK)

Central Computer Facility	40,000 DM
Checkout	767,000 DM for 700 vehicles
	1,204,000 DM for 1,400 vehicles
	1,641,000 DM for 2,100 vehicles

7.2.3 Stations

The components are:

- Station Guideway
- Station Structure
- Station Equipment

Costs for station guideway are the same as that given in Section 7.2.1, Table 7-1. Table 7-3 lists the costs of the other two components in the station. It is assumed that all stations are equipped with sufficient equipment to handle four docking points per direction.

7.2.4 Operational Support

The facilities for operational support consist of:

- Energy supply facilities
- Vehicle storage depots
- Maintenance and repair facilities
- Cleaning facilities

It is difficult to determine the exact requirements for these facilities without having details of the specific systems, such as, the number of cabins and the possibility of integrating the depots and repair facilities into other city structures.

Table 7-3

PRICES FOR STATION COMPONENTS (AVERAGE SIZE NETWORK)

Station Component	Unit	Price per Unit in DM	
		KK3	KK12
Station Structure	Piece per station		
Double rail		510,000	-
Suspended rail		150,000	100,000
Top-mounted rail		150,000	100,000
Station Equipment	Piece per station		
Elevators		85,000	85,000
Station Computer & passenger processing facilities (Fare automats, etc).		180,000	130,000

For the purpose of this report, the results obtained from a feasibility study of deploying the Cabintaxi in Marl [26,54] will be used. It is assumed that the vehicle depot consists of:

- 12 crossing switches (price per switch = 250,000 DM)
- 6 main track switches
- 1.75 km of double track, i.e., 3.5 km (suspended/top-mounted) having a capacity of
- 400 vehicles (KK3)
- 200 vehicles (KK12)

Using the figures given in Table 7-1 for the guideway cost, the costs for the facilities required for operational support can be obtained (Table 7-4).

Table 7-4

COSTS FOR FACILITIES NEEDED FOR OPERATIONAL SUPPORT
(AVERAGE SIZE NETWORK)

Component	Unit	Price per Unit in DM
Energy Supply		250,000
Vehicle depots	depot	
- KK3		15,600,000
- KK12		
Double track		15,600,000
Suspended track		19,870,000
Top-mounted		19,000,000
- Cabinlift (1)		
Maintenance & Repair		
- KK3		2,500,000
- KK12		1,500,000
- Cabinlift		250,000
Cleaning Facility (2)	depot	263,000

Notes:

(1) For the Cabinlift, no special depot is planned. The storage and cleaning is carried out in the maintenance and repair facility.

(2) A cleaning facility for each depot would service 400 KK3 and 200 KK12 vehicles. For the Cabinlift, no special cleaning facility is planned.

7.2.5 Vehicles

The total capital requirements for vehicles will depend on the number of cabins for personal conveyance and the number of vehicles for service and recovery. The price per vehicle is given for different types in Table 7-5.

Table 7-5.
COST PER VEHICLE TYPE (BASED ON THE NUMBER OF VEHICLES USED IN AN AVERAGE SIZE NETWORK)

System	Vehicle Type	Capital Requirements in DM
KK3	Cabin	39,000
	Service	180,000
	Recovery	260,000
	Cargo vehicle	30,000
KK12	Cabin	61,000
	Service	180,000
	Recovery	260,000
	Cargo vehicle	30,000
Cabinlift	Cabin	180,000
	Service	180,000
	Recovery	260,000
	Cargo vehicle	30,000

7.3 Fiscal Considerations

To account for the different useful lifes associated with the various system components, the capital requirements per year or the so-called annual investment is often used. For each system component and assuming a zero salvage value, the annual investment K is related to the total capital requirement A by the following equation:

$$\frac{K}{A} = \text{Annuity Factor} = \frac{(1 + i)^n \cdot i}{(1 + i)^n - i}$$

where:

K = annual investment cost

A = capital requirements for the system component

n = useful lifetime for the particular component

i = interest rate

The useful life of the system components, together with their annuition factors, are shown in Table 7-6. An annual interest of 6%, or i = 0.06 was used.

Table 7-6

USEFUL LIFE SYSTEM COMPONENTS AND THEIR APPROPRIATE ANNUITY FACTORS AT 6%

Components	Useful Life	Annuition Factor
Guideway		
- Guideway beams	50	0.0634
- Supports	50	0.0634
- Switches	35	0.0690
Central Control		
- Computer	10	0.1359
- Checkout	10	0.1359
Stations		
- Guideway		(see above)
- Building	50	0.063
- Equipment		
Elevators	15	0.1030
Computer, passenger processing	10	0.1359
Operational Support		
- Power supply	25	0.0782
- Vehicle depots	30	0.0726
- Maintenance & repair facility	50	0.0634
- Cleaning facility	25	0.0782
Vehicles	10	0.1359

7.4 INVESTMENT COSTS FOR A 1 km FUNCTIONAL SYSTEM

In order to get an idea of the expected order of magnitude for a single system, the capital requirements as well as the annual investment for a 1 km functional system (facilities and vehicles) will be determined using the component cost information provided in the previous sections. The computation will be based on the construction of a 1 km system, using switches, stations, etc., the layout of which is assumed to be plausible on the basis of available planning done to this point.

Since the capital requirements depend heavily on the number of stations, costs for two alternative station spacings will be presented.

	Average Distance Between Stations	
	Case 1	Case 2
KK3 Network	500 m	700 m
KK12 Network	700 m	900 m
Cabinlift	250 m	500 m

Table 7-7 gives the capital requirements for this 1 km functional system. It is obtained from having performed a trade-off analysis between the number of units and the cost per unit. These analyses are relatively involved and will not be presented here. The corresponding annual investment using the annuity factors given in Table 7-6 is given in Table 7-8.

7.5 OPERATIONAL COSTS

The factors which affect the operational costs are many and varied. An important part of these factors stems from the operational capacity expected from the system in terms of seat and passenger kilometers per year. No specific case will be considered in this section. However, the estimates given below will allow determination of costs for specific applications.

7.5.1 Personnel

Since all the Cabintaxi/Cabinlift systems are operated automatically, a substantial part of the personnel cost in operational areas have been eliminated when compared with conventional systems. The personnel requirements between the KK3, KK12, and the Cabinlift are not too different. The following information (see Page 7-11) is therefore applicable to all three systems.

Table 7-7

CAPITAL REQUIREMENTS FOR A 1 km FUNCTIONAL SYSTEM (AVERAGE SIZE NETWORK)

	Capital Requirements in DM (Rounded Off)	
	Case 1	Case 2
KK3	13,700,000	12,500,000
KK12, Double rail		
off-line	11,200,000	10,500,000
on-line	9,000,000	8,700,000
Suspended rail		
off-line	8,600,000	8,100,000
on-line	6,900,000	6,700,000
Top-mounted		
off-line	8,300,000	7,800,000
on-line	6,600,000	6,500,000
Cabinlift		
Suspended	7,900,000	7,200,000
Top-mounted	7,600,000	6,900,000

Table 7-8

INVESTMENT COSTS (INCLUDING VEHICLES) FOR A 1 km FUNCTIONAL SYSTEM (AVERAGE SIZE NETWORK)

	Investment Costs in DM (Rounded Off)	
	Case 1	Case 2
KK3	1,016,000	924,000
KK12, Double rail		
off-line	806,000	753,000
on-line	644,000	621,000
Suspended		
off-line	640,000	601,000
on-line	512,000	496,000
Top-mounted		
off-line	616,000	578,000
on-line	496,000	479,000
Cabinlift, suspended	644,000	568,000

Transportation and Operational Personnel

Transportation personnel are those who cover the video monitors and telephone service in the system headquarters, whereas operational personnel are those who have responsibility for track sections from the various decentralized network control stations. Table 7-9 gives the salary requirements of the transportation and operational personnel per system kilometer based on an average size network. For example, 0.276 person year will be required to cover the function of the transportation personnel in the KK3 system. It is obtained as follows:

0.0375	person per system km for video monitoring
0.0250	person per system km for telephone service
0.0625	person per system km

For a 20-hour operational day (+2.5 shifts per day) and 207 productive work days per person, per year, and 365 operational days per year, the result is:

$$(0.0625) \times (2.5) \times \left(\frac{365}{207}\right) = 0.276 \text{ person per system km}$$

Table 7-9

SALARIES FOR TRANSPORT PERSONNEL PER SYSTEM KILOMETER (AVERAGE SIZE NETWORK)

System	Personnel Type	Person-Year Costs in DM	Person per System km	Costs per System km in DM
KK3	Central Headquarters	40,000	0.276	11,040
	Network Control Points	35,000	0.098	3,430
KK12	Central Headquarters	40,000	0.276	11,040
	Network Control Points	35,000	0.098	3,430
Cabinlift	Central Headquarters	40,000	0.276	11,040
	Network Control Points	35,000	-	-

Technical and Cleaning Personnel

The determination of the costs associated with the technical and cleaning personnel is usually accomplished in three steps. The first step is to determine the requirements in terms of person-hours per year for each individual component, independent of the number of components in the system. The second step is to compute the total person-hours required per subsystem, and the last step is to integrate the time and salary required for all subsystems. Since the computation for the second and the last step require information on the capacity and usage of the system, they will not be presented. Table 7-10 lists the basic requirements of time and salary for individual components.

Table 7-10

TIME REQUIRED FOR TECHNICAL AND CLEANING PERSONNEL FOR THE INDIVIDUAL SYSTEM COMPONENTS

Personnel	Unit	Time Expenditure h/y	Costs per h[1] in DM
Maintenance and Repair	h/track km	23.50	24.15
Guideway	h/track km h/support h/switch	23.50 0.80 6.90	24.15 18.12 27.17
Building Structures	h/1 million DM capital needs	180.00	18.12
Power Supply	h/track km	75.50[2]	27.17
Equipment (Mechanical and Electronic)	h/1 million DM capital needs	4,150.00	24.15
Vehicles	h/vehicle KK3 h/vehicle KK12 and Cabinlift	66.35 112.73	27.17 27.17
Cleaning			
Stations	h/station	365.00	18.12
Vehicles	h/vehicle	25.34[3]	18.12

NOTES: (1) 1,656 productive hours per year.

(2) 1.5 substations per km.

(3) 1.53 persons per year per 100 vehicles at 1.656 productive hours per person per year.

The time requirements listed in the table are obtained as follows: maintenance and repair of the guideway includes traveling along the guideway, checking the guideway carriers and making small repairs, checking the supports, and doing the necessary painting on the support girders. Maintenance and repair of the power supply includes small repair and replacement of current rail sections. Detailed maintenance and repair manuals will be used for the maintenance and repair of the vehicles, including the major vehicle tests.

Cleaning of the station is to be done daily. Mechanical techniques will be used basically for interior and exterior cleaning of the cabins.

Administrative Personnel

Administrative personnel cannot be arranged according to system components. The number of personnel is strongly dependent upon the requirements placed on the finished system and should be planned exactly with these requirements in mind.

In conventional public transport systems in the Federal Republic of Germany, some 15 percent of the overall personnel costs are ear-marked for administrative personnel. Whether this proportion is higher or lower for the systems considered here will be known only after their deployment.

7.5.2 Energy

The target value for the energy use of the vehicles is:

Vehicle	Energy Use/Seat km	Unit
KK3	0.10	kWh
KK12	0.06	kWh
Cabinlift	0.05	kWh

Aside from the energy used by the vehicles, the energy requirements of the station must also be considered. These values include:

Unit	Energy Use (Standard Value)
kWh/year/station	32,500

This usage for the stations is based on the value of 4.5 kW and a 20 h daily operational time.

The cost of energy used in this report is assumed to be 0.1 DM/kWh. This value could vary as much as 60 percent depending on the relationship of the system operator with the local power supplier.

7.5.3 Material

In a similar manner to the process used for technical and cleaning personnel, the material use must be determined in several steps.

Chiefly, the material will be calculated in units of amount of use/component. Since no practical values gained from system use are available here, the material use must be calculated on the amount of the capital outlay for the individual component. Table 7-11 contains this information in percent of the capital outlay according to each component.

Table 7-11

COSTS FOR MATERIAL USE FOR COMPONENTS IN PERCENT OF THE CAPITAL OUTLAY FOR AN AVERAGE SIZED NETWORK

Components	Percent of the Capital Outlay
Guideway	
- Guideway beam	0.06
- Supports	0.01
- Switches	1.00
Building Structures (above ground)	0.20
Energy Supply	0.60
Equipment	
- Central computer	1.00
- Elevators	0.60
- Passenger processing equipment	1.00
- Check out	3.00
- Mechanical facilities	2.0 to 3.5
Vehicles	5.70

7.6 SYSTEM COSTS

The costs for a complete system can be determined with a reasonable accuracy only if the network topology and the transportation conditions under which the system will operate are known. In order to provide an idea of the expected order of magnitude with regard to overall system cost, this section will present the results of two planning studies for deploying Cabintaxi KK3 and KK12 in the cities of Marl [26,54] and Munich [39], Federal Republic of Germany.

7.6.1 Cabintaxi in Marl [26,54]

The feasibility study using the Cabintaxi in Marl was based on a town of 92,000 population (forecasted for 1985) with specific destination discretionary travel. The procedures used in this study have been covered briefly in Section 8.3.

Figure 4.93 of Section 4.12.2 is a sketch of the 52 km network. Sixteen hundred vehicles are required (see Section 4.13.3.3). The main features of the constructed facility are 60 km of guideway carrier, 1695 supports, 186 main track switches, 14 side track switches, 57 stations (4 place stations), and 5 (6 place) stations. The stations are of the off-line type and the guideway has two levels.

The traffic capacity of the system is planned to be 291,000 passenger km per day, consisting of 75,400 passenger trips at an average trip distance of 3.86 km per passenger trip. Based on a 28.3 percent seat usage, the operational capacity of the system becomes 1,030,000 seat km. The mean weighed indirect route factor (Section 4.12.2) is about 1.7.

The capital requirements were calculated to be 572,875,000 DM (at 1976 prices). Using an interest rate of 6 percent, the annual investment would be 44,061,000 DM.

The annual operational costs are as follows:

Personnel	9,593,000 DM
Energy	4,771,000 DM
Material	6,344,000 DM
Insurance	403,000 DM
Total Operational Costs per Year	21,111,000 DM

Without considering Federal measures which may apply to such a system, the total cost (the sum of operational cost and the annual investment) is 65,172,000 DM.

Based on the data given, it is seen that:

Specific operational cost	
DM/passenger-km	0.23
DM/seat-km	0.07
DM/average trip	0.90
Specific overall costs (interest rate 6 percent, without subsidies)	
DM/passenger km	0.72
DM/seat km	0.20
DM/average trip	2.79

7.6.2 Cabintaxi in Munich, [39]

This study was concerned with the use of KK12 cabins to provide feeder and distribution services in connection with the conventional rail system in the northern part of the City of Munich (133,000 population) for the year 1985. The operational mode of this system would be a schedule controlled line operation.

A description of the approximately 39 km network can be found in Section 4.12.3. About 350 KK12 cabins are required to provide the service.

The main structural features are 39 km of guideway, 1060 supports, 28 switches, and approximately 58 stations (each with 4 KK12 cabin places). The stations are of the on-line type and the guideways are double level.

The traffic capacity of the system is planned to be some 279,000 passengers km/work day, corresponding to 85.7 million passengers km/year. The accompanying operational capacity is 1,107,000 seat km/work day, corresponding to 339.84 million seat km/year. The planned usage level for these figures is 25 percent. The total public traffic effected in a work day is 63,000 journeys/day/direction.

The costs are calculated according to 1974/1975 prices. The capital requirements for investment amount to 256,000,000 DM. Using an interest rate of 6 percent, the annual investment would be 18,174,000 DM.

The annual operational costs are obtained as follows:

Personnel	3,117,000 DM
Energy	3,790,000 DM
Material	2,818,000 DM
Total Operational Costs per Year	9,725,000 DM

The total annual costs, then (without subsidies), are 27,899,000 DM. Again it is seen that:

Specific operational costs:	
DM/passenger km	0.11
DM/seat km	0.03
Specific overall costs:	
DM/passenger km	0.33
DM/seat km	0.08

It should be noted that only seated positions (no standing places) are offered exclusively when evaluating the specific tasks of the Cabintaxi. Therefore, direct comparisons with other forms of transport is not possible.

8. BACKGROUND UP UNTIL SYSTEM INTRODUCTION

In addition to the problems of technical development, there are a number of other problems that must be resolved prior to the introduction of Cabintaxi/Cabinlift as a public transport system. The funding for the development of the Cabintaxi/Cabinlift system is partially subsidized by the Federal Government because of its being a relatively high development risk project. Moreover, in order to decrease the developmental risk and to minimize developmental failures, the work was backed up by carrying out in parallel theoretical investigations including, for example, system costs and public acceptance. Practical application of the system in a large complex network is being investigated in the form of feasibility studies. This work, coupled with the actual experience gained with regard to safety and reliability from operating the system in a small demonstration facility, will be used to work out the overall certification specifications for the operation of an automatic urban transport system. These issues will be discussed in more detail in the following sections.

8.1 GOVERNMENT REQUIREMENTS

The PRT-System, which is the basic concept of the Cabintaxi system, probably comes closest to the user's ideal of what an urban transport system should be. At the same time, however, it presents the highest developmental demands with respect to functional performance, safety, reliability, and economy. The high developmental costs make it impossible for a single firm to develop this type of transport system to maturity with its own financial resources. In this case, and others like it, the government of the Federal Republic of Germany has made available research funds as subsidies through the German Federal Ministry of Research and Technology (MORT).

The appropriate policies stipulate that funds from this source can be used for research and development if the projects under consideration fulfill the following criteria:

1. The companies' headquarters as well as the development and research capabilities and facilities must be located within the Federal Republic of Germany, including West Berlin.
2. The project and research associated with it must support and improve the capability of the German economy and German science.

3. The necessary qualifications and capabilities for carrying out research and development of the type required must be available.
4. The company must be viable and must demonstrate that it can provide an auditing system suited to accounting for the spending of public funds.
5. The firms involved must be prepared to work together on this project with scientific and technical institutions and their equipment.

Participating industrial firms are required to share with the government the total cost of the project. For governmental participation, funds are available (especially in resulting research and development) in accordance with the following criteria:

1. Important technological projects demanding a large amount of resources together with a high risk of technical scientific success which are not within the capabilities of a single developmental firm.
2. Further development and technical utilization of important new knowledge and experience resulting from work carried out in public owned scientific resources, such as technical schools, research centers and other research facilities.
3. Research and development in which German industry is engaged in competition with foreign countries having similar programs funded by their governments.

The MORT is supported in the planning of transport systems, in the evaluating of proposals, and in checking the progress of on-going or completed projects by:

1. the Industrieanlagen-Betriebsgesellschaft GmbH (IABG) in Ottobrunn near Munich, which acts as project monitor,
2. panels of consultants,
3. periodic status seminars and other presentations, and
4. research and development results.

Up until the end of 1976, 76,700,000 DM had been spent for the development of the Cabintaxi/Cabinlift system, including the Cabinlift in Ziegenhain. The MORT supported these developmental costs with federal contributions in the

amount of 59,000,000 DM. The DEMAG and MBB firms contributed 17,700,000 DM of their own resources.

An additional 50,900,000 DM in developmental costs is planned by the end of 1979 which will include a demonstration facility. The MORT will assume 43,900,000 DM of costs. The remaining 7,000,000 DM must be financed by the developmental firms. Therefore, by the end of 1979 the overall developmental costs of the Cabintaxi system will be 127,600,000 DM.

The developmental costs are divided over the calendar years as follows:

Year	MORT millions of DM	ARGE Cabintaxi DEMAG/MBB millions of DM
1969 to 1971		3.0
1972	3.0	0.8
1973	12.4	3.1
1974	11.3	2.8
1975	16.2	4.0
1876	16.1	4.0
1977	15.7	2.9
1978	13.9	2.3
1979	14.3	1.8
Total	102.9	24.7

8.2 DEVELOPMENT PHASES

The program nay be considered as consisting of four overlapping phases:

1. Analysis and conceptual phase
2. Component development phase
3. Testing phase
4. Demonstration phase

The various phases of the development steps up to the introduction of the Cabintaxi system as a public passenger transport system are presented in Figure 8-1.

Preliminary studies during the analysis and conceptual phase provided information on the special characteristics of the system. Included in this

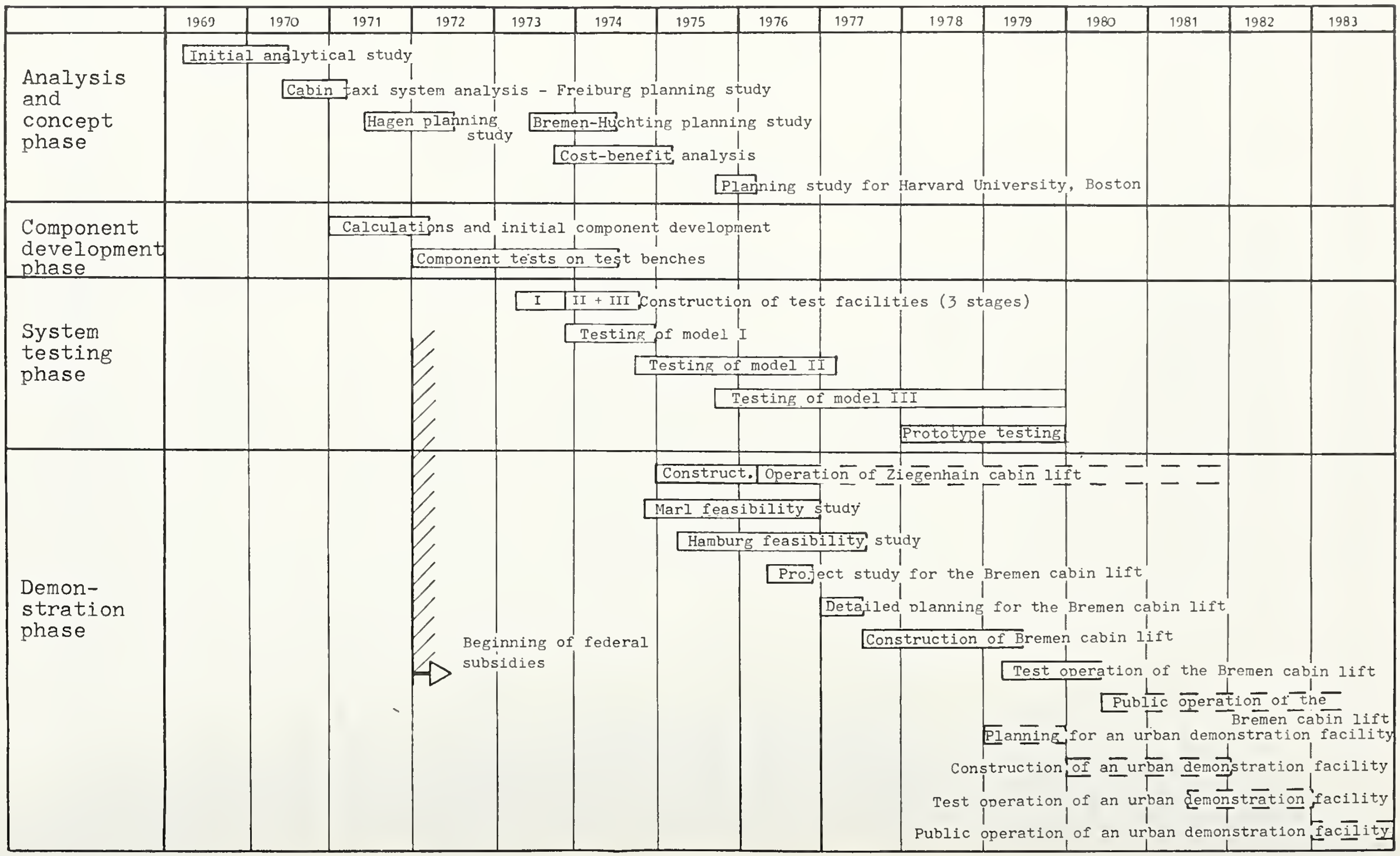

Figure 8-1. Developmental Steps: Cabintaxi/Cabinlift

phase are: planning studies, cost-benefit analysis, sociological, psychological, ergonometric, economic, and legal investigations. These studies were intended to answer as many questions as possible before the actual beginning of development.

Analytical studies for novel local transportation systems based on unconventional technology began in 1969. The system was to incorporate as many of the advanced features as possible of present public transport systems and private automobiles.

Initial findings, published in the middle of 1970, showed that the basic concept of the Cabintaxi system offered an attractive alternative to the partly chaotic transport situation in cities and population centers. The concept was worked out in detail as part of the planning studies for the cities of Freiburg (published in May 1971) and Hagen (published in the middle of 1972). The results indicated that the Cabintaxi would indeed be a suitable alternative.

On the basis of the positive results of these studies, the Cabintaxi project was incorporated on 1/1/1972 as part of the federal government sponsored "public urban transport" program. It created a broader basis for subsequent development activities. From this time on, 80% of the costs were financed by MORT.

The component development phase started in 1971. It forged ahead with full steam when federal subsidies were obtained. As a result, when system testing began on the test facility in Hagen, all the important single components had already been bench tested. Tests were also conducted with various groups of people to estimate the acceptance of the system by future users.

The Ziegenhain Cabinlift facility, built in 1975, was the first system of the demonstration phase. The automatic "horizontal elevator" was based on the technology of the Cabintaxi using only components that had been sufficiently tested at the Hagen test facility. The facility has, up to now, demonstrated its economy and reliability. It is considered by the Urban Mass Transportation Administration of the U.S. Department of Transportation as a potential bidder for the Downtown People Mover program.

The next demonstration facility will be the Cabinlift system for the central hospital in Bremen. The system plan calls for an elevated top-mounted guideway 2.8 km long, with 11 switches and 17 stopping points at clinics or administrative buildings. Sixteen automatic cabin vehicles will be used to provide transport for passengers and goods. The trip will be self-controlled when the destination is given. Operational guidance with planned disposition of "clean" and "dirty" cabins is generally automated and monitored by an operator at central control.

The present plan for the construction of the Bremen facility is as follows:

1/1/77 - 6/30/77	Detailed planning
7/1/77 - 3/31/79	Construction, fabrication and installation of hardware
4/1/79 - 9/30/79	Beginning of operation
10/1/79 - 3/31/80	Operational testing
4/1/80	Partial transfer to the hospital administration
7/1/80	Transfer of the total system to the hospital administration.

This system has already met all technical requirements of public transport with respect to safety, reliability, availability and minimal enviromental impact. The end of the demonstration phase and with it the complete development of the Cabintaxi system will occur with the building of a reference facility for public passenger transport. It will then be possible to reach further conclusions regarding the willingness of the public to accept such a system, and the possible problems with vandalism and other criminal acts since the system will be unmanned.

Positive results from feasibility studies and the demonstration facility in Bremen from a technical and economical point of view will be required prior to construction of such a facility. Detailed planning for the public reference facility will begin in 1979.

The reference facility should form the central part of the planned total network. After finishing the reference facility (planned to be about 1981/1982), the facility should be operated to serve the public. Initially, observational personnel could be placed at all stations to help and advise the passengers with the new system. These advisors would help passengers to more easily use the automatic fare machines. In the second operational phase, these observational personnel will be removed from the stations and full automatic public operation will be tested.

On the basis of experience gained from public operation, the appropriate operational and structural modifications can be made in the basic planning for the total network. In a step by step fashion, then, the rest of the network will be built.

8.3 THEORETICAL INVESTIGATION

A large number of studies in areas of costs, public acceptance, and ergonomic issues were carried out in parallel with the technical development of the Cabintaxi system. In the following sections, the works on feasibility and costs are presented in detail.

Feasibility Studies

Several candidate areas which would be suitable for the utilization of the Cabintaxi/Cabinlift system were first selected for feasibility studies. The selection was largely based on investigation of parameters such as system configuration, traffic pattern, potential usuage, existing transport service and the projected economics of the Cabintaxi service.

For these areas that have been selected for feasibility studies, exhaustive studies are made of transportation, construction, and operation with special consideration to cost. Comparative study is done relating the Cabintaxi system to those conventional urban transport systems that can provide a comparable level of service. At the present time, two feasibility studies for the use of Cabintaxi systems are still being carried out, the 3-seat small vehicle system for the city of Marl [26], and the 12-seat vehicle system for a suburb of Hamburg [4].

For each feasibility study, several working groups are involved. One group assumes the task of overall traffic planning. The second group consists of an on-site team of construction engineers responsible for translating the results as they apply to the local site. The third group is responsible for the operational problems of the Cabintaxi and those conventional urban transport systems that can provide a comparable level of service.

To obtain initial transport data for the feasibility study, general transport plans of the community and other similar available data are used.

General transport plans are usually set up by the community as a basis for future transportation planning. They are reviewed and updated at 5 year intervals. The plans contain:

- the mobility of the population in the area studied, i.e., information regarding the number of trips per household per day and/or number of trips per person per day
- the daily distribution of the requirements for transportation
- the amount of traffic between the various parts of the areas served
- division of the travel according to professional, educational, discretionary, and business related
- the transportation system used, i.e., individual automobile vs. public transport, and
- the behavior of the traffic with respect to its use of transport system (i.e., motive for the selection of a given transport system according to the criteria of travel time, journey distance, travel cost and/or availability).

The data available with regard to the various characteristics listed above is modified using an estimated modal-split factor assuming a new and attractive transport system. Using this modified set of data the studies concluded that the Cabintaxi transport system appears very attractive with respect to other new types of transportation systems. It is, however, recommended that the estimation of the modal-split factor for any new transport system be confirmed by questioning of the public.

The model which has been developed from the present transportation demands and the transport distribution formed the basis for the prognosis of the future traffic flow between the various transportation areas. The estimation of the percentage of Cabintaxi users was accomplished by using the estimated mobilization factor and the modal-split function.

The planning of network alternatives (also see Section 4.12) was done on the basis of the available information for travel from source stations to destination stations for the new public transport system. Housing and high density work areas, as well as shopping centers, schools, hospitals, etc. are to be served by stations. After assigning the individual stations to the various traffic cells in the area being studied, the expected number of passengers boarding and deboarding can be calculated. Statistical simulation was used to study variations of the Cabintaxi system, leading to comparison and improvement of the network alternatives.

The final network configuration to be considered was found using exhaustive and step-wise evaluation, selection, and improvement of the different network configurations. Operational transportation and city architecture viewpoints were considered. After determining the selected network or a few network alternatives which were to be studied further, the traffic and operational aspects of these systems were dynamically simulated using realistic parameters. The results yielded further network improvements and the basis on which the Cabintaxi system would be compared with those conventional urban transport systems that can provide a comparable level of service in cost-benefit analysis.

Cost Studies

During the development of a new urban transport system, investment and operational costs must be given special consideration. For example, in 1974 the Cabintaxi system was subjected to cost-benefit analysis with regard to its possible service as a public transport system. The city of Hagen was used as an example. The Cabintaxi system was compared to the bus system. The significant result (for a 1990 time frame) was that the Cabintaxi was superior to the bus in Hagen having considered all the attributes such as time saved, no environmental impact, and reduction of funds for urban transport. An interest rate of 6 1/2% was used for this study.

Cost efficiency studies are also being carried out as part of the feasibility studies for the Cabintaxi system in Marl [26] and Hamburg [4]. The costs of the Cabintaxi system are compared with costs that would be encountered by the introduction of a conventional but further developed comparable transport system. Operational and investment costs are determined for both systems. To obtain operational cost, dynamic simulation is used to assess, for example, the operational capacity and the required number of vehicles. Before capital cost can be estimated, the networks of both systems must be designed in detail. In the case of Cabintaxi, this was accomplished using the general features of several network alternatives. As part of the sensitivity analysis, variations of a few critical traffic parameters (for example, variations of the modal-split function, and the amount of usage) are investigated as to their effect on the cost.

8.4 QUESTIONS REGARDING CERTIFICATION

In the Federal Republic of Germany, technical facilities used for passenger transportation must be officially certified. There are a number of laws, ordinances and guidelines which must be considered. When applying these regulations it must be distinguished whether the system is to be used exclusively within a given facility (hospital, factory) or is to be used as a public facility.

The following laws and guidelines are pertinent in this discussion:

- Passenger transportation law (PBefG) [43]
- Federal law on construction of buildings (BBauG) [44]
- Building codes of the individual states (LBO) [45]
- Guidelines for the construction and operation of elevator systems (AufzVO) [46]
- Guidelines covering the construction and operation of light rail systems (BO Strab) [6]
- The federal enviornmental protection law (BImSchG) [47]
- Work protection regulations
- Accident prevention regulations
- Guidelines from the Society of German Engineers [VDI]
- Guidelines of the Society of German Electronic Technicians [VDE]
- Guidelines from the German Institute of Standards. [DIN]

The Cabintaxi/Cabinlift system differs from existing conventional urban transport systems such as subways and light rail systems in that it is automatically controlled and driverless. Conventional transport systems require various levels of competence from the vehicle driver which is reflected in the ordinances and guidelines that have been established. Present ordinances and guidelines are not yet sufficient to consider completely automatic public transport systems. Until these guidelines are amended, fully automatic operation of transport systems is only possible by special permission and/or special certification. In the development of the Cabintaxi/Cabinlift system, whenever possible, consideration has been given to existing guidelines such as those covering the construction and operation of light rail systems, e.g., BO Strab and the DIN.

Certification of the first operational Cabinlift system in Ziegenhain (see Appendix) was accomplished using the elevator ordinances [46] with certain sections excepted. Since the handling of modern automatic elevators requires no special knowledge by the person using the system, the elevator ordinances [46] could, by special permission, easily be used for this "simple" automatic transportation system in Ziegenhain. It remains to be determined whether or not these same ordinances can also be used for more complex dedicated or internal systems.

While the technical system development of new applications is accomplished systematically from experience gained from earlier developmental steps built one on top of the other (the test facility in Hagen, Ziegenhain Cabinlift, the internal facility for the hospital in Bremen), the certification for public systems does not necessarily follow as a consequence of certification for internal facility dedicated systems. New guidelines and standards for internal systems and public systems must be established in view of the different safety requirements.

8.4.1 The Certification of Internal or Facility Dedicated Cabinlift Systems

The internal facility is to serve the interest only of those responsible for the facility. No public usage would be made of this system. In addition, the facility would be run exclusively by responsible personnel, whereby the responsibility for its safe operation is limited to this part of the company's employees. Therefore, the certification procedure for an internal transport

system, whether it carries only goods, or goods and passengers, is less complicated than certification of a public system.

For internal facilities, the long and involved procedures such as presenting the detailed construction plans and the procedures for final determination of the plans may be avoided. Permission for the construction of the facility is to be obtained from the local authorities according to the state building codes [45]. Among other things, the static characteristics of the facility, minimal interval distance to other buildings, security of signal, and other electrical components need to be inspected.

Whereas the Cabinlift at Ziegenhain has been certified according to the elevator ordinances [46], officials in Bremen are currently checking as to which available legal regulations apply before giving permission to build the facility. Acceptance testing of the vehicles and on-going monitoring of operations are not required for the internal facility system.

There are many regulations regarding operation and transport technology which need to be conformed to by the Bremen system, many of which are also necessary to the public urban system. Therefore, operational experience regarding safety and reliability to be carried out on the Bremen system will also help to accelerate the certification procedure for implementing the Cabintaxi as a public urban transport system.

8.4.2 The Certification Procedure for the Cabintaxi as a Public Urban Transport System

As mentioned at the onset, there are at present no special guidelines or regulations regarding the certification of fully automated urban transport systems.

According to the passenger transportation law PBefG [43], the Cabintaxi is a "rail system of special structural design similar to a light rail system." Consequently, the BO Strab must be referred to. The BO Strab is at the present time being amended with regard to fully automated systems.

The first step in the certification procedure is the formal submission of final plans according to the PBefG. This is intended to insure that public and private interests in the planning of the facility are considered.

In the procedure for final submission of plans, the advantages and disadvantages of a Cabinrail system are examined with regard to operational technology, transport economy, city planning, construction, and emission guidelines. These aspects as well as the foreseeable effects on other administrative areas, for example, supply operations, private residences, and land owners are considered. The concerned federal, state, and local authorities and the other various concerned parties are requested to give their comments on the plans. The citizens of the community in which the facility is to be erected are also given the option to comment on the plans. All comments received have to be considered before the authority is allowed to make a final decision. Each rejection or acceptance decision must be justified, otherwise the procedure is open to legal question.

After the final decision is made to accept or reject the plans, neither public nor private interests can make changes. In case the required land cannot be obtained by purchase, confiscation procedures are allowed with the legally binding planning decision in hand. However, the present law allows a private citizen to express his opposition to the final plan at the administrative court. This can hinder the beginning of construction until the final decision is made. Therefore timely work in publication of the proposed project can serve as a lever for quick completion of this procedure. Citizens who will be affected by the judgement have claim to settlements.

The licensing for construction and operation may be applied for when the plans are submitted, but the license cannot be approved until the plan is accepted. This license, which can only be granted to a viable operator, includes:

- The licensing of stationary facility,
- The licensing of vehicles, and
- The licensing of the operation.

The construction of station buildings and overpasses must be licensed according to the applicable state building codes. In some cases it may not be possible to comply with the regulations regarding spacing between buildings and the new construction. In these cases, exceptions can be made based on the final decision of the submitted plans.

The construction of the operational facilities may begin only after the final decision on the submitted plan has been made, and license has been legally granted and the proposed construction approved.

After the construction is finished, it must be inspected by the authorities before it is allowed to open to the public. The system can begin operation only after an additional license covering mode of operation (fares, operating hours, carry-on luggage, animals, etc.) is granted by the authorities.

9. FINDINGS AND CONCLUSIONS

The findings and conclusions resulting from this study are grouped into the categories of System Concept and Operation, Development and Deployment, System Certification, and Passenger-Related System Aspects. Although these observations are focused on the Cabintaxi/Cabinlift systems, some are addressed to urban transportation systems in general. Findings and conclusions peculiar to the Ziegenhain system may be found in Appendix A.

9.1 SYSTEM CONCEPT AND OPERATION

- The design philosophy for the Cabintaxi/Cabinlift systems, to fabricate a set of AGT modules or "building blocks," has resulted in a system concept with broad flexibility for application. Modularization and prefabrication of guideways and stations suggests potential savings in both construction time and specific system development costs.

- The asynchronous vehicle-follower longitudinal control system permits platooning of vehicles, mixing of vehicle sizes, and increased potential for high link-capacity.

- The hierarchical approach to control system implementation will permit safe system operation, albeit with degraded performance, in the event of loss of the central control computer or malfunctions at the station level, thus possibly improving system availability.

- The capability for dynamic route selection should enhance the system's load balancing, availability, and schedule maintenance characteristics.

- The innovative design of the switches strives for the merging of platoons of vehicles with minimal propagation of speed reduction in the platoons, thus further improving the link capacity potential. Although platooned merge operational tests have been carried out at the test facility, the <u>behavior</u> of vehicle platoons in the merging switches

determined through simulation should be verified in a live environment.

- The guideway is narrow and aesthetically pleasing, thereby greatly enhancing the probability of public acceptability in urban environments. The unique over and under guideway configuration permits operation of both supported and suspended vehicles on the same guideway, and represents an extremely small cross section for a two-way guideway. The small cross section is made possible by the lightweight design of the vehicles. Single lane configurations and single lanes merged with double lane configurations are also available, permitting considerable choice in specific system layout and capacility.

- The vehicles are compact, lightweight, and generally attractive. The ratio of the maximum loading to empty vehicle weight is 33% for the KK3 vehicle, and 50% for the KK12 vehicle.

- With the exception of the special application (e.g. hospitals) Cabinlift vehicle, the vehicles to date have been designed for seated passengers only. The current dedication to seated passengers has allowed greater latitude in acceleration, deceleration, and jerk parameters, as well as smaller (height) vehicles at the expense of capacity. It is recommended that investigations be conducted as to the feasibility of increasing the passenger capacity of the Cabinlift vehicles (including standing places) and utilizing them in public transport systems, including coupling of the vehicles into trains.

- The current system will accommodate grades of up to 15% and speeds up to 10 m/sec. Higher speeds may be desirable in order to reduce travel time when the distance between stations increases. To obtain higher speeds, additional design and development would be required in the propulsion, braking, and vehicle control systems. In addition, accompanying investigations

should be carried out relative to guideway stress and curvature limitations, noise, energy use, passenger comfort, and operational and facility costs.

- The feasibility for installation of low-speed track sections should be investigated. This would make possible the use of smaller curve radii in some sections of the guideway than those required for higher speeds, and would result in even greater flexibility in suiting the overall guideway system to existing city structures.

- The use of linear induction motors for the Cabintaxi systems offers significant advantages over friction drives relative to grade, noise, wear, and all-weather operations. In addition, recovery of disabled vehicles by pushing or pulling is facilitated by the minimal friction characteristics of the LIM. However, the use of LIMs could increase guideway costs because of stringent requirements for alignment of the reaction rail. There also exists the possibility of greater energy consumption due to the inherently less efficient motor.

- The system concept calls for capability to couple vehicles for "push-away" recovery of disabled vehicles, and ultimately for train-type operations. A mechanical coupler device is undergoing evaluation at the test track, and a proposed electrical connector is also being separately evaluated. However, the most significant considerations relative to coupling are currently in the design phase and planned for implementation sometime after Bremen. These are: the requirement to override the automatic headway assurance (collision avoidance) system to permit vehicle closure, the distribution of control functions between coupled vehicles, and the requirement for communication links over the entire guideway rather than in discrete areas as presently implemented. This feature is deemed extremely desirable for systems where rapid recovery of disabled vehicles in minimal time is required.

- There is currently no overload protection in the KK3 and KK12 vehicles. It is recommended that these vehicles be made secure against departure in an overloaded condition.

9.2 DEVELOPMENT AND DEPLOYMENT

- The development philosophy adopted by the manufacturers can be characterized as an intensive, well-ordered, and directed effort aimed at proving the feasibility of basic design assumptions. The results of the present iterative design/test process have provided the rationale for selection of various engineering specifications and proven the validity of the selected design.

- Consideration of those elements of the system specifically related to safety and reliability was addressed in the development process, and provision was made for their inclusion in the design. These concepts were not generally reduced to practice, but remained as design goals and as inputs to a continuing safety and reliability analysis. This staged development has resulted in a functionally well engineered system.

- The system will require additional design and test activity in the areas of safety and reliability prior to eligibility for public deployment in a multivehicle configuration. Particular safety related elements yet to be fully incorporated into the system include a vehicle-borne, fail-safe backup for the present headway assurance system, redundant fail-safe merge protection, and a capability in the vehicle redundant electronics for a fail-safe comparison of safety critical control elements. A desirable reliability enhancement is the planned expansion of the vehicle computational electronics into a triply redundant voter configuration. The ease with which these designs can be reduced to practice and assimilated into the present control system is an unknown factor, thereby introducing a degree of risk in development and deployment of the system.

- A key aspect of the Cabintaxi test program is the assessment of the level of maintenance required for the system. In general, maintenance planning for the command and control system is incomplete and quite fluid at this time. It is highly dependent

on data currently being gathered on failure rates, modes, ease of repair, and personnel training levels. It is recommended that more emphasis be given to real-time monitoring of failure modes within an operating vehicle.

- The fact that there has not yet been a multivehicle network deployment of the system, leaves open the question of achieved performance versus expected performance in the areas of service availability, schedule maintenance, network management efficiency, maintenance strategies, failure recovery management, computer network operation and reliability, and system deployment schedules and experience.

- The design specification for the command and control system did not rely on any one design guide, but utilized portions of military and commercial guides assembled together to form a "best guess" of system requirements. One significant output of this program will be a "design spec" reflecting Cabintaxi experience oriented specifically to automated urban systems.

- The development philosophy has resulted in considerable attention being directed to the gathering of test data and the integration of all subsystem components. The test facilities at MBB and the use of the Hagen Test Track have provided a test bed for realistic appraisal of both design and integrated system operational problems.

- Considerable attention appears to have been spent on "front end" engineering design tasks, such as noise and signal margin analysis, subsystem and component testing, and interface control. The results have been impressive with test experience at Hagen, indicating very few problems with the basic command and control system hardware or operational concepts.

- Realibility and failure mode predictions have been undertaken for all electronic components developed for MBB, as well as the propulsion controller developed for DEMAG. Failure mode and effect analyses have also been undertaken on each functional block, in order to determine potential impacts on

safety and operability. This analysis is a continuing task in the trade-off process as new designs are considered for inclusion. The overall impression of the Cabintaxi test program is that it is thorough in both subsystem and system level testing, and that the results are being incorporated into new designs through an effective iterative process of evaluation and redesign. System level and subsystem testing have indicated good agreement between predicted and actual operational characteristics.

- An important and beneficial aspect of the development program has been the extensive use of computer simulation, both as an aid to the technical design process and as a tool for evaluating efficient network control strategies.

- Significant differences in simulation have been observed between the results obtained utilizing idealized networks, and those obtained when real networks with actual topographical constraints were considered. Networks are particularly sensitive to maintenance, storage, and recovery techniques. Therefore, it is necessary to model particular networks and their actual constraints to determine system performance for a given urban community. The simulation tools developed for Cabintaxi should prove extremely valuable in planning for and optimizing performance of applications, although their true effectiveness has yet to be validated through actual experience with a deployed system.

- The manufacturers have been and are vigorously pursuing optimization of the crashworthiness of the Cabintaxi vehicles with minimal injury, and a non-lethal "brickwall" crash being the goal, even though all AGT control systems must be designed for "fail-safe" operation.

Other Recommendations with Regard to Development and Deployment

- Further investigations are desirable relative to all Cabintaxi/ Cabinlift systems as to the options for positioning of depots along the network and the resulting empty cabin distribution, as well as systematic and generalized studies of passenger flow and handling in the station for all modes of operation including mixed modes.

- It should be determined whether climate and weather conditions in the United States would require the installation of air conditioning on the vehicles.

- When deploying these systems, the system operator should assure that the cabins are illuminated by separate emergency lighting, in case of power failure, and that the power supply for the stations is made secure, in order to maintain the station control electronics and station lighting. In addition, magnetic cards or keys should be considered for use in facility-dedicated systems to minimize unauthorized use of the systems.

- Heavily used stations should have stairways which are at least 1.80 m wide to accommodate three lanes of pedestrians. For scheduled mode operation with trains and a station arrangement other than ground level, the construction of escalators may be required to accommodate larger traffic volumes and/or passenger convenience.

- Definitions for the concepts of "reliability" and availability" as they apply to transport systems should be uniformily established. A reliability data bank for failure rates of components of AGT systems should be developed and made generally available.

9.3 SYSTEM CERTIFICATION

Due to the lack of specific guidelines for certification of automated transportation systems in Germany, the manufacturers have chosen to introduce the system in a stepwise fashion to gain experience in the process,

and to pave the way for certification and acceptance of automated transport systems. The following recommendations have been formulated from the experience to date.

- The requirements for certification of public transport systems which are presently in effect in Germany must be further modified with respect to automatic driverless operation.

- The use of systems which have been allowed certification by exceptions to existing guidelines should provide experience with safety, reliability, and acceptance, which will help pave the way for formulation of revised certification requirements. In order to ease the certification process, initial systems should be installed at nonpublic facilities, such as factories, hospitals, etc., because these facilities pose fewer problems.

- A prototype facility for public transport should be developed to investigate reliability, the handling of system malfunctions with respect to safety and rescue procedures, the behavior of passengers, the acceptance of such a system by the population, and the impact on transportation modal split.

9.4 PASSENGER-RELATED SYSTEM ASPECTS

- The revised edition of "Ergonomic and Safety Technology Demands of New Types of AGT Systems," [20] when it becomes available, should be consulted for additional information on the passenger-related aspects of the Cabintaxi Systems.

- Ride quality/comfort of the Cabintaxi systems should be measured in terms of the RMS amplitudes of acceleration for each of the six degrees of freedom for the bandwith 0.1-10 Hz, as well as according to the procedures given in Section 4.2 of the International Standard ISO 2631.

- Although the interior noise levels of the various Cabintaxi vehicles were found to be subjectively acceptable, objective measurements should be made.

- Barrierless fare collection is employed in the Cabintaxi/Cabinlift systems, as in the conventional transit systems in West Germany. While this mode of operation may be acceptable in the KK3 type of system, where a ticket buys a car rather than a seat, the barrierless fare collection approach may not be appropriate for the United States market with KK12 or other large vehicles. Therefore, a barrier fare-collection system should be considered for the larger vehicle Cabintaxi/Cabinlift systems for use in the U.S.A.

- A more definitive study on the public's response/acceptance to AGT systems in general, and Cabintaxi systems in particular, should be carried out.

- The conflicting requirements of preventing, on the one hand, the inadvertent opening of a door of a vehicle, and on the other, passenger emergency egress from the vehicle in a timely fashion (e.g., via rescue vehicle or transport to nearby station) in the event of need, should be given further attention in the design of Cabintaxi systems. In particular, U.S. experience has shown that the ability of passengers to exit from a stalled vehicle of an elevated system without outside assistance would be problematical.

- The manufacturers have designed the stations and vehicles for the Cabintaxi systems to minimize the problems of vandalism, and specific steps have been taken to prevent passengers from being able to insert any objects into the ventilation grill of the cabin heating system. Strong emphasis should be given in all AGT systems to the prevention of vandalism, since the systems lack the supervisory presence of a driver.

- Unless the interior of the vehicle is effectively and totally nonflammable, the vehicle should be equipped with an automatic trifluortromomethane fire extinguisher system.

- The current design of the stations permits access to the guideway on supported vehicle systems. Since there is no provision for automatic detection of people or objects on the guideway, this situation could prove hazardous. Therefore, restricting doors or other solutions should be provided.

Handicapped and Elderly

Principally, public transport should be designed to serve as large a number of handicapped and elderly as possible. The primary problem for the transportation of wheelchairs in the use of the Cabintaxi systems, as implemented at the Hagen test center, is the gap in the vertical dimension between the station platform and the door opening of the vehicles.

The needs of the handicapped should be considered in the design and construction of the stations and vehicles of new transport systems. Different requirements must be established for the different groups of handicapped or elderly (e.g., partially blind, blind, paraplegic, those whose mobility has been decreased by age, etc.). Necessary special measures are apparent with regard to people confined to a wheel chair.

The following general recommendations for provision for the elderly and handicapped are offered [20]:

a) Station Entry (Access)

1. Parking should be provided close to boarding points with the needs of the handicapped in mind, (for example, reserved parking places and avoidance of any barriers to wheelchairs, etc.).

2. Entry and exit corridors within the boarding point premises should be short.

3. The entry to the station should be negotiable by wheelchairs. In the case that elevation differences cannot be avoided architecturally, at minimum ramps should be provided.

4. Ramps should have a maximum slope of 6%.

5. Access corridors and ramps should be covered with a hard nonslip surface which is suitable for wheelchairs.

6. Access corridors, steps, ramps, and elevator must be well lit (min. 120 LuX).

b) Accommodations Inside the Station

7. When designing accommodations for information and use of the facility, the possible limited mental and physical abilities of the elderly and handicapped must be taken into consideration.

8. In areas where tickets are obtained and/or validated, whether automatically or by a system employee, space should be provided to place crutches and luggage.

9. Seating should be provided on the platform.

10. When stations are located on the first floor or first and second basements, a lift (elevator) should be available.

11. The lifts should be reached without steps. The opening time of automatic doors should be sufficiently long.

12. The door width of the lift should be approximately 90 cm, or a minimum of 80 cm, to allow entry of a wheelchair.

13. The lift car should have at least the following minimum interior dimensions:

    Width: 110 cm
    Depth: 40 cm

    The space requirements to turn a wheelchair are 135 x 135 cm.

14. The control elements for the lift car are to be positioned between 90 cm and 140 cm above the floor, and at least 20 cm from the door opening.

15. When stationary steps are used, the step profile should be selected so as not to endanger the handicapped, that is, the height of each step = 16 cm, and depth of the step (horizontal) = 31 cm.

c) Entry and Exit from the Car

17. Entries and exits to and from the cars should have no steps and no gaps (which would present difficulty to the handicapped).

18. Hand grips and stationary rails should be provided to assist in entry into the car.

19. The installation of appropriately designed car and station doors contribute a great deal to the safety of the elderly and handicapped particularly in the platform areas.

The points listed under a) should be integrated into the design of the station entrances. The design requirements of the system under b) and c) are to be realized, for the most part, through proper standards of construction. Furthermore, recommendations such as those in 19 (automatic station doors and car doors) are a question of funding. In the case of smaller cars, the unfavorable ratio of the cost of such accommodations to the total investment must be considered. The expenditure should be critically matched to the intended use. For example, installation of automatic station doors will be a consideration for stations in the neighborhood of hospitals, rest homes, or housing for the elderly.

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APPENDIX A

OPERATIONAL ASSESSMENT OF THE CABINLIFT SYSTEM AT ZIEGENHAIN

CONTENTS

ILLUSTRATIONS

TABLES

A1. INTRODUCTION

The Ziegenhain Cabinlift System is a single-vehicle AGT shuttle transporting patients, medical staff, equipment, and food between the out-patient clinic and the main hospital building of the Ziegenhain Hospital complex, located in the district of Schwaim-Eder in the Federal Republic of Germany. The two buildings are situated about 578 m (1897 ft) apart. Figures A1-1 and A1-2 show the vehicle and a section of the elevated guideway.

The system consists of a selected subset of the overall Cabintaxi/ Cabinlift technology modified to fit the specific application. It has been operable since March, 1976 (in daily service since July 1 of 1976) and was designed, built, and placed in operation in nine months by the German firms DEMAG Fördertechnik and MBB (Messerschmitt-Bolkow-Blohm GmbH). The contract price was DM 2.056 million ($822,400), and the final delivered cost was DM 2.2 million ($880,000). The shuttle system was included in the planning for the new clinic building. The Cabinlift guideway structure also carries utility service lines from the main hospital building to the clinic, thus eliminating the need for duplication of these facilities.

Figure A1-1. Vehicle Entering Station

Figure A1-2. Guideway, Pylon, and the Hospital Station

A2. TECHNICAL DESCRIPTION

This section provides a brief description of the technology of the Cabinlift system at Ziegenhain, West Germany. The system was derived from a more sophisticated Cabintaxi/Cabinlift technology program underway at the test facility in Hagen, West Germany, (see main report).

A2.1 System Overview

The Cabinlift system is an automated demand-responsive (for discretionary travel) shuttle system capable of operating 24 hours per day. It is comprised of one suspended vehicle, 578 m (1897 ft) of single lane dual directional elevated guideway without switches, a retrieval and maintenance vehicle, and two on-line stub end stations located within the hospital buildings. The control system is an uncomplicated hard-wired system involving no computer or central control facility. The vehicle is shuttled between the two stations governed by its linear induction motor controller which adjusts the vehicle's velocity based on passive guideway indicators. The Ziegenhain hospital system requires no formal maintenance building or sophisticated maintenance facilities. A sketch of the guideway layout is shown in Figure A2-1. Figure A2-2 shows the vehicle and a curved section of the elevated guideway viewed from a station. Figure A2-3 shows a portion of the guideway and a support column. Figure A2-4 is a block diagram of the Ziegenhain Cabinlift major subsystems (vehicle, guideway, stations, and operational back-up) broken down into components and subassemblies. Notable aspects of the system design are described under appropriate separate headings in subsequent text.

The prime system-level design requirements were as follows:

- automatic operation
- a shuttle trip time of 3-4 minutes
- a system design life of 30 years

  vehicle life of 10 years
  guideway life of 50 years

- an acceleration or "jerk" rate compatible with movement of food (soup in open containers)

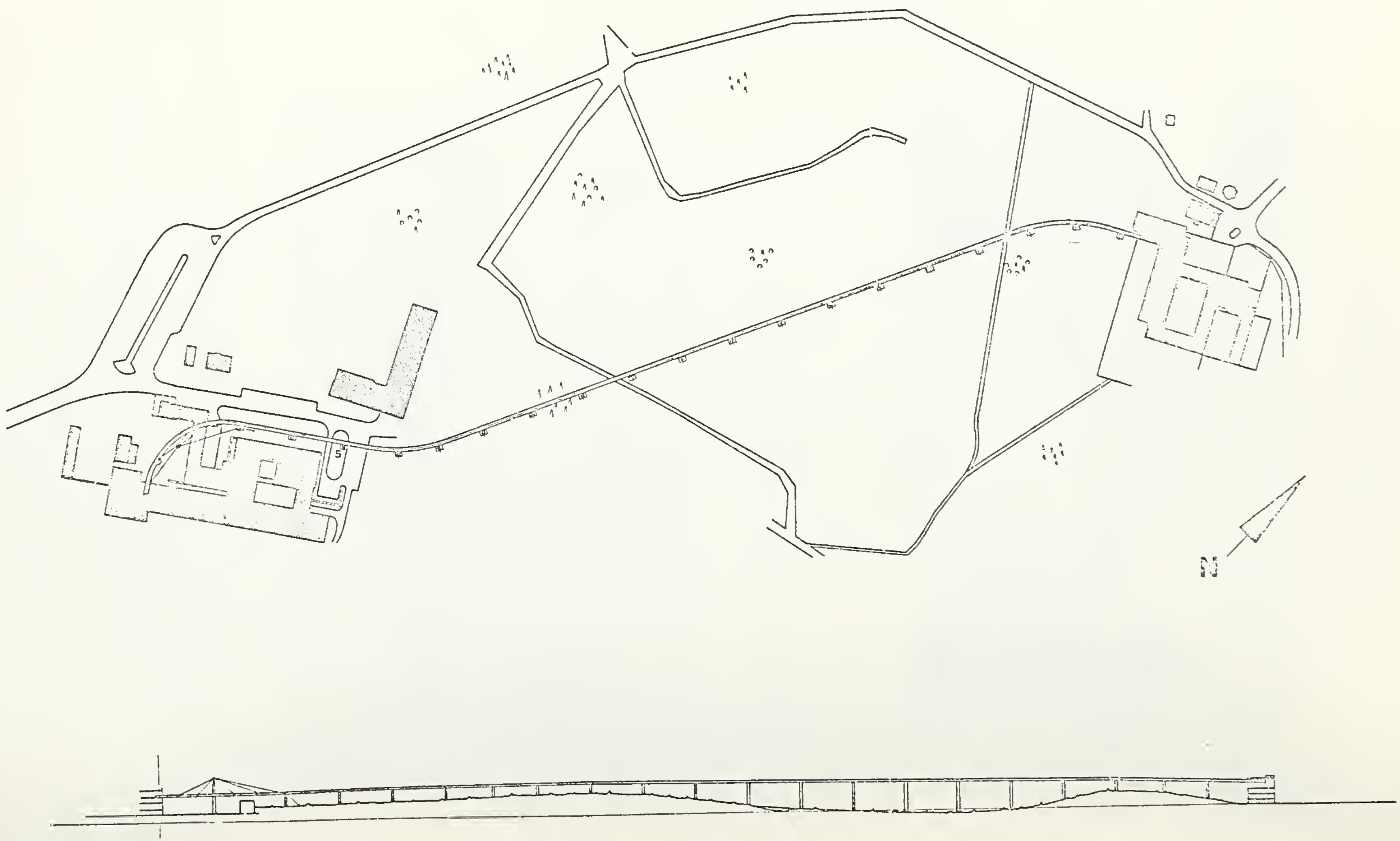


Figure A2-1. Layout of Ziegenhain Cabinlift Guideway

Figure A2-2. Vehicle, Guideway and Hospital

Figure A2-3. Vehicle, Guideway and Support Column

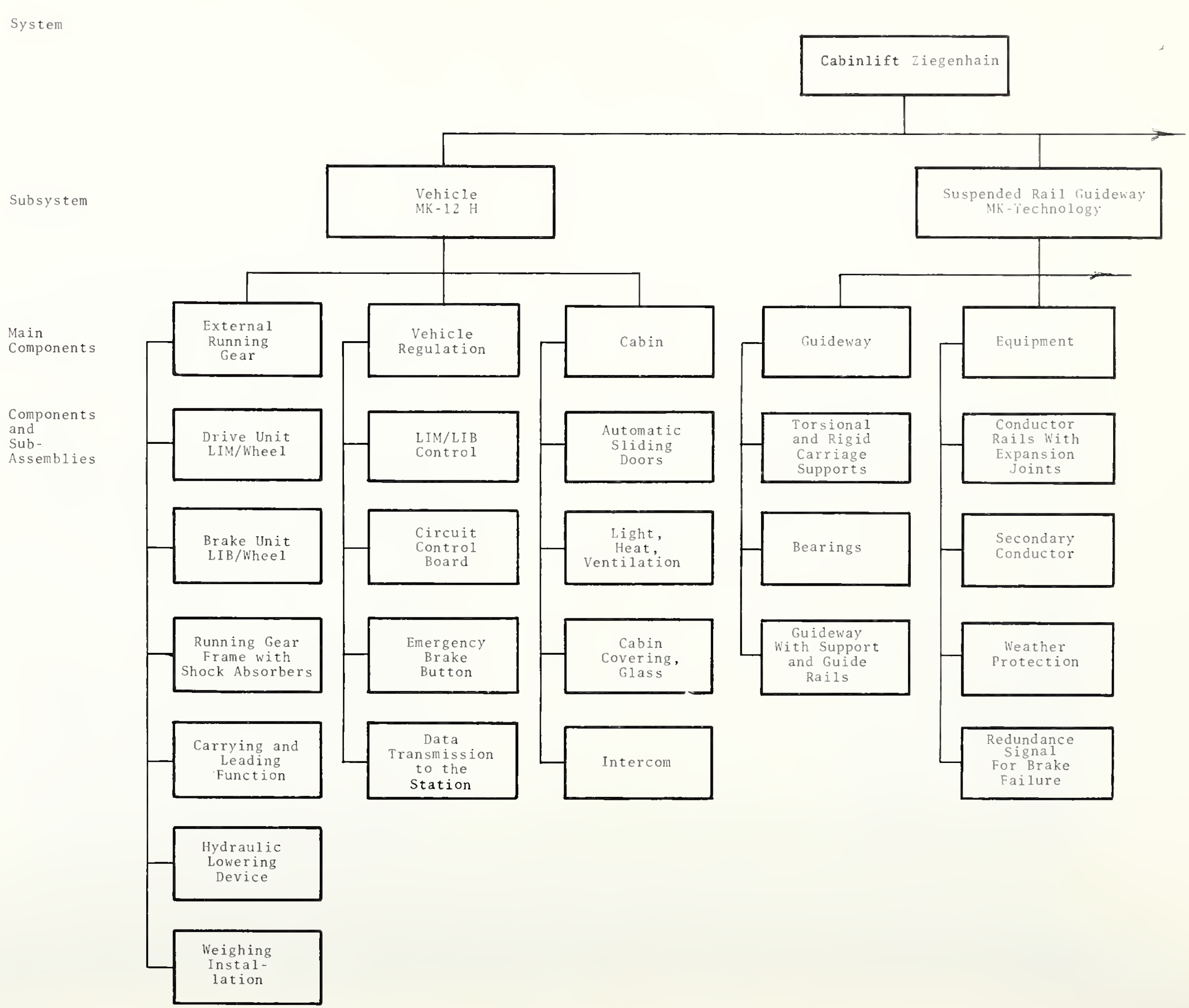


Figure A2-4. System Block Diagram

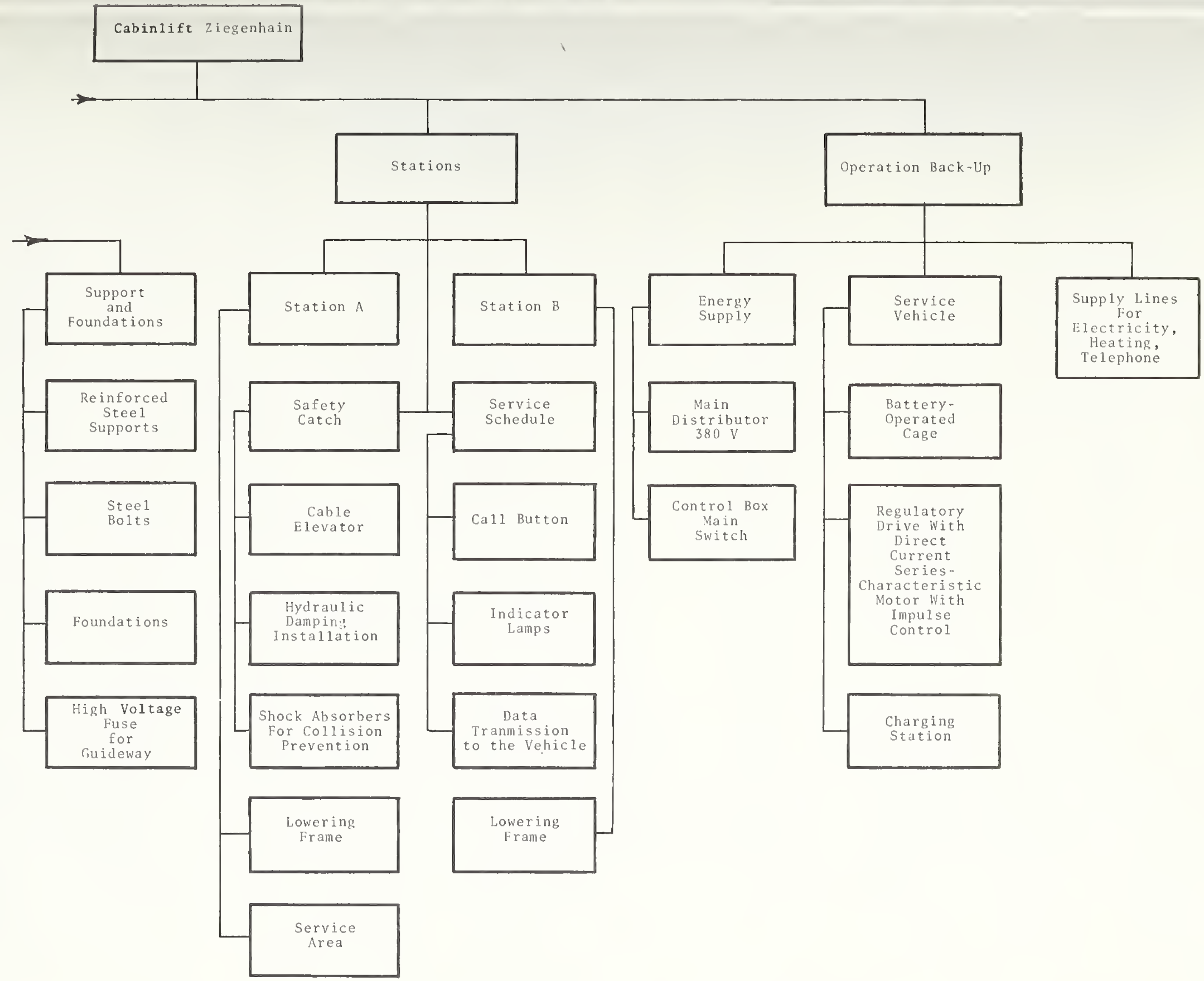


Figure A2-4. System Block Diagram (Cont.)

- a safety system comparable to vertical elevator safety and hence capable of being licensed under elevator codes.

These include:

- Mechanical means to stop the vehicle at the station in case of a brake failure.
- Independent auxillary drive for the operational vehicle to reach one of the two stations in case of power failure.
- Quick access to malfunctioning vehicle at any position along the guideway using a track guided maintenance vehicle.
- Means for presenting derailing.

<u>Operations</u>

Table A2-1 summarizes the principal operational characteristics of the system. The system is capable of three different modes of operation:

1. routine,
2. priority, and
3. emergency or express traffic.

Normal personnel and goods transport would be included under the routine classification. A call button is located in each station to order a cabin in A light display informs the user as to the present position of the cabin, in station A or station B and/or in route towards station A or towards station B. These stations are connected with a control cable along the guideway through which this information is transferred. The start command is given from inside the cabin via pushbutton.

Persons having priority can reserve the vehicle at a station using the key, and in addition can control the vehicles speed in a range of from 0 to 60 m/s.

For emergency traffic, normal demands for the cabin can be overriden and the cabin may be immediately reserved for any station. Users are informed of this reservation by a display within the stations.

Because of heavy usage by patients and visitors, thereby hindering the internal hospital traffic, magnetic card operation was installed in June of 1977. This equipment, which prevents unauthorized use of the Cabinlift, has already

Table A2-1

ZIEGENHAIN CABINLIFT SYSTEM OPERATIONAL CHARACTERISTICS

System Performances	
Max. theoretical one-way capacity	98 passengers/h
Max. practical one-way capacity (80% of max. theoretical)	78 passengers/h
Availability	On demand, 24 h/day (currently 16 h/day, 5:00 AM-9:00 PM)
Type Service	Point-to-point shuttle between two buildings with a single vehicle on a single guideway
Traveling Unit	Single suspended vehicle
Interior Noise (mean level)	59 - 65 dBA
Exterior Noise (mean level in the hospital room next to station A, windows open)	43 - 47 dBA
Vehicle Performance	
Cruise velocity	6 m/s - 21.8 km/h (13.5 mph)
Service acceleration	0.35 m/s^2 (1.15 ft/s^2)
Service deceleration	0.35 m/s^2 (1.15 ft/s^2)
Max. jerk	0.3 m/s^3 (0.98 ft/s^3)
Emergency deceleration (with 1000 kg load)	1.0 m/s^2 (3.28 ft/s^2)
Emergency deceleration (unloaded)	1.5 m/s^2 (4.92 ft/s^2)
Stopping precision in station	10 mm (0.4 in.)
Degradation if guideway is wet	No degradation
Degradation for ice and snow	Minimal degradation
Vehicle design capacity	12 passengers or 1000 kg payload
Energy consumption	1.17 kWh/veh.-km
Stations	
Type	2 stations integral with out-patient clinic and main hospital
Type boarding	Level through doors at end of vehicle
Ticket or fare collection security	Not applicable, self-contained system within hospital complex

Table A2-1. (Cont.)

Max. wait time	7.3 min
Vehicle in station dwell time	As required
Station spacing	578.2 m (1896.9 ft)
<u>Individual Service</u>	
Privacy	Not applicable, one large shuttle veh. at hospital complex
Transfers	None
Stops	Non-stop
Accommodations	Seated, standees, and patients in hospital beds
Security	No special considerations
Instruction	Staff training
Comfort	Heated and ventilated (no air conditioning)
Cargo capability	Hospital equipment, beds, food serving carts
<u>Reliability and Safety</u>	
Vital safety features	Motor overspeed protection, for service braking two LIM-brakes and 6 hydraulic brakes, for emergency brake 4 spring brakes, plus safety-arresting cable brake.
Fail operational features	Operation to nearer down-hill station under battery power. 4 spring-loaded brakes
Strategy for passenger evacuation	Maintenance vehicle operates on top of guideway. Evacuation cage hangs adjacent to vehicle with platform under vehicle door.
Strategy for removal of failed vehicle	Battery power to wheelmotor and operation to nearer station or towing by maintenance vehicle

Table A2-1. (Cont.)

System lifetime (design goal)	30 years
Guideway lifetime (design goal)	50 years
Vehicle lifetime (design goal)	10 years

Personnel Requirements

Vehicle and stations are unmanned. Hospital elevator maintenance staff function as diagnosticians for routine maintenance. A DEMAG technician is available within an hour for major problems. Vehicles are hand cleaned by custodians.

Cabinlift System Physical Description

Vehicle:	
Length, overall	3.78 m (12.4 ft)
Width, overall	1.96 m (6.4 ft)
Height, overall	2.35 m (7.7 ft)
Weight, empty	2200 kg (4850 lb)
Weight, gross	3200 kg (7050 lb)
Doorway width	1.13 m (3.7 ft)
Doorway height	2.0 m (6.6 ft)
Step height	level

Suspension

Type	Solid-rubber tired wheels on double bogie (hard riding bogie with soft sprung body)
Lateral guidance	Solid-rubber tired guide-wheels

Propulsion and Braking

Type, location, and no. motors	2 double-camb horizontal linear induction motors. Both LIMs on one side of vehicle
Type drive	Linear motor drive
Type power	380 V ac, 3-phase
Power collection	Power collectors on bogie, power rails on guideway
Type service brakes	Dynamic through LIB plus electric-hydraulic drum brakes (6 wheels)
Type emergency brakes	Mechanical drum brakes (4 wheels)
Emergency brake reaction time	15 ms

Table A2-1. (Cont.)

<u>Switching</u>		None
<u>Guideway</u>		
Type		Steel box-beam
Supports		Concrete centilever arm and one pylon support
Gauge		1250 mm (4.1 ft)
Standard span		28.8 m (94.5 ft)
Overall cross section width		1860 mm (6.1 ft)
Overall cross section height		1350 mm (4.4 ft)
Guideway Structural weight		500 kp/m (69.0 lb/ft)
<u>Installation</u>		
Guideway Envelope width, incl. columns	including space for maintenance vehicle	4330 mm (14.2 ft)
Guideway Envelope height		4700 mm (15.4 ft)
Max. grade at site		3.4%
Min. horizontal turn radius		39.5 m (129.6 ft)
Construction process		Prefabricated supports and sections, stations are three modular components
<u>Staging Capability</u>		Sections can be operated while others are under construction

been proven at the test facility. Various classes of personnel have cards with various priorities. For example:

- General personnel: routine
- Doctors : priority

A2.2 <u>CONTROL</u>

The design of the control system for the single-vehicle Cabinlift shuttle at Ziegenhain was predicated on the fact that it did not require a central control system, a sophisticated multi-vehicle longitudinal control system, a vehicle collision avoidance system, or a mechanism for vehicle switching. The system has been introduced to meet the specific requirements of the hospital

environment allowing three different modes of operation - routine, priority and emergency - as described in Section A2.1.

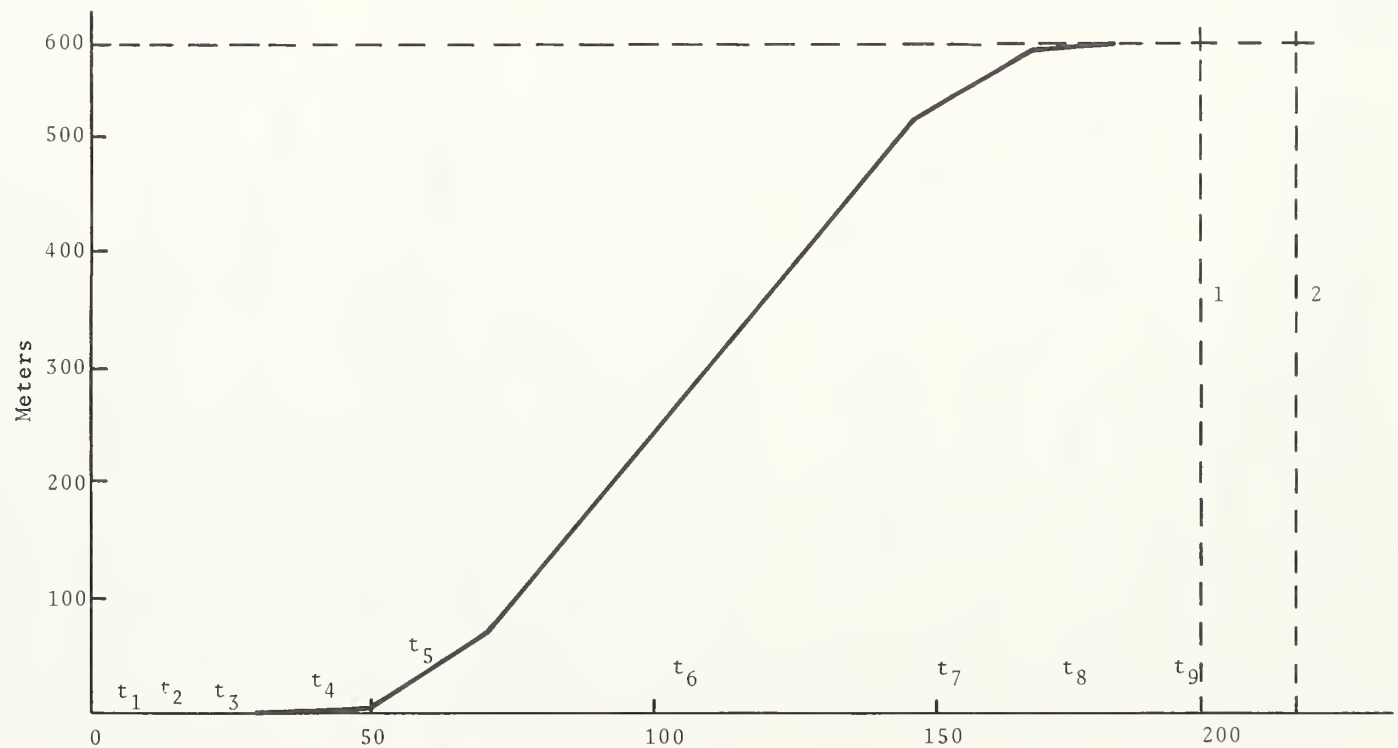
The principal control element is the linear induction motor (LIM) controller on board the vehicle which governs velocity, acceleration, deceleration, and brake initiation. The vehicle's velocity is conveyed to the controller by dual tachometers attached to the load-bearing bogie wheels.

Velocity transitions are triggered when the controller encounters signals elements situated at discrete points in the guideway. The signal elements in the guideway are passive and consist of permanent magnetic bars. The controller on the vehicle contains magnetic detectors in the form of reed relays interconnected to recognize the N-S orientation of the magnets; and the electronics thereby cause an acceleration or deceleration of the vehicle depending on whether the N or S pole of the magnet is encountered first in the direction of the vehicle's motion. The acceleration or deceleration is limited by the controller to the desired velocity.

Before departure the station and vehicle doors are closed in unison and the cabin is raised. At this point it is determined whether or not the cabin exceeds it's maximum allowable gross weight and that the loading is not too asymmetrical. Twenty-seven to thirty-two seconds ($t_1 + t_2 + t_3$) are required to carry out this operation. Figure A2-5 is the distance-time diagram in which the values for the various phases are given, such as closing the doors, vehicle weighing, start acceleration, travel, braking, and docking. The half-cycle time is the time for a simple trip, that is from station A to station B without the return trip; the processes of door opening and closing as well as boarding and deboarding are contained in the half-cycle time.

If the cabin is properly loaded, it slowly leaves the station with a speed V_H = 0.3 m/s (0.98 ft/sec), and thereafter accelerates with b_B = 0.35 m/s^2 (1.15 ft/sec^2) to the predetermined speed of v_s = 6 m/s = 21.6 km/h (Approximately equal to 13 mph). Jerk is limited to 0.3 m/s^3 (0.98 ft/sec^3). After a further 38 seconds the top speed is reached.

Braking is initiated before reaching the destination when the magnetic indicator with the appropriate orientation is encountered. The vehicle uses



t_1 = 10s: Reaction time for door closing
t_2 = 2s: Interval till door closing and locking
t_3 = 15-20s: Time span for lifting, weighing, and release (load dependent)
t_4 = 21s: Route travel at speed of 0.5 m/s
t_5 = 20s: Acceleration at 0.35 m/s to 6 m/s
t_6 = 75s: Travel at top speed

t_7 = 20s: Braking at 0.35 m/s^2 to 0.5 m/s
t_8 = 21s: Route travel at 0.5 m/s
t_9 = 10s: Docking
Journey cycle A-B-A:
t_{Zmin} ~440 sec = 7,3 min
1- Journey time from A to B
2- Half-cycle time

Figure A2-5. Distance-Time Graph

linear induction brakes (LIB) and hydraulic wheel brakes to bring the speed down to 0.3 m/s (0.98 ft/sec). At mid-brake point, the correctness of speed reduction is tested by a speed control device set in the track. The speed monitoring works with an inductive approach ignition primer and a time relay. If a failure to achieve the desired slow speed is recognized, current is shut off and emergency braking takes place. Figure A2-6 shows the system velocity profile (see Section A3.4 for further discussion of braking and safety features).

After switching off the propulsion in the station, the cabin is hydraulically lowered onto a fixed frame to allow deboarding without negotiating a step. For emergencies, an emergency handle is located above the door. The activation of the emergency handle initiates the emergency braking. Thereafter, the main propulsion is switched off and the vehicle can be driven to one of the two stations under auxillary power.

A2.3 GUIDEWAY

The guideway at Ziegenhain is a single track, elevated structure operating between two stations and is designed for two-way operation of a single suspended vehicle. The tracking and support rails, power rails, magnetic sensors for vehicle control, and communication circuits are attached to the outside of a steel girder some 1.2 m (3.93 ft) by 0.5 m (1.64 ft) wide. It also serves to carry heating pipes, telephone lines, and electrical cables from the main hospital to the out-patient clinic. A cross section of the guideway is depicted in Figure A2-7. An aluminum cover (Figure A2-8) encloses the structure on two sides providing weather protection as well as aesthetic enhancement.

The guideway contains a narrow curve with a radius of curvation of 39.5 m (130 ft). The track is not cambered.

The guideway is supported by arms cantilevered from prefabricated reinforced concrete columns or piers spaced at about 28 m (91.86 ft) intervals (Figure A2-9). The supports with the smallest height measure are 6.73 m (22.1 ft). Those with the highest measurements are 17.73 m (58.2 ft) from the top edge of the footings to the top edge of the girder. The cross-section measurements are 790 x 660 mm (2.59 x 2.17 ft) and 1250 x 800 mm (4.10 x 2.62 ft) respectively, in height from the top edge of the foundations. Support columns decrease in diameter with increasing height.

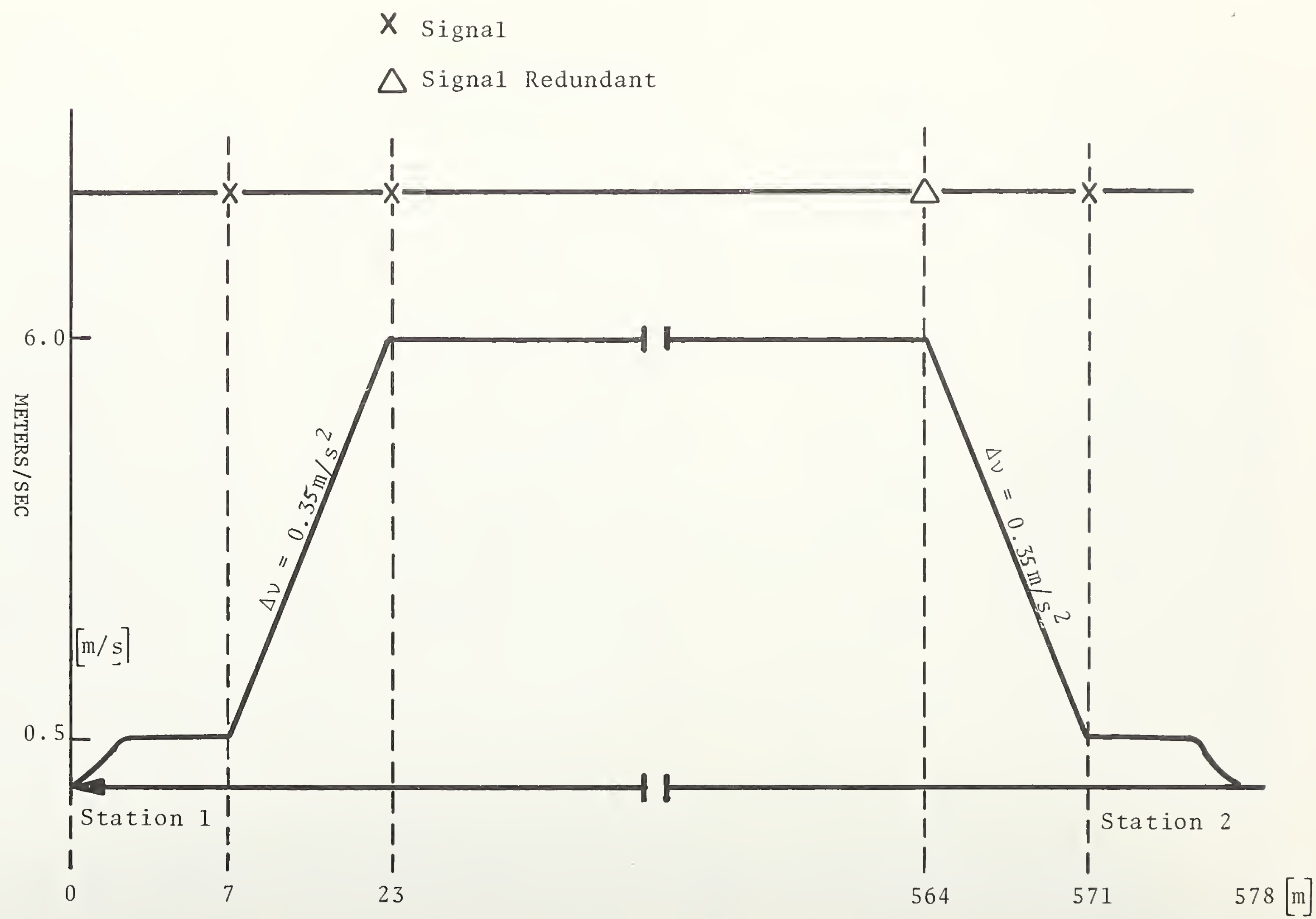


Figure A2-6. Velocity Profile

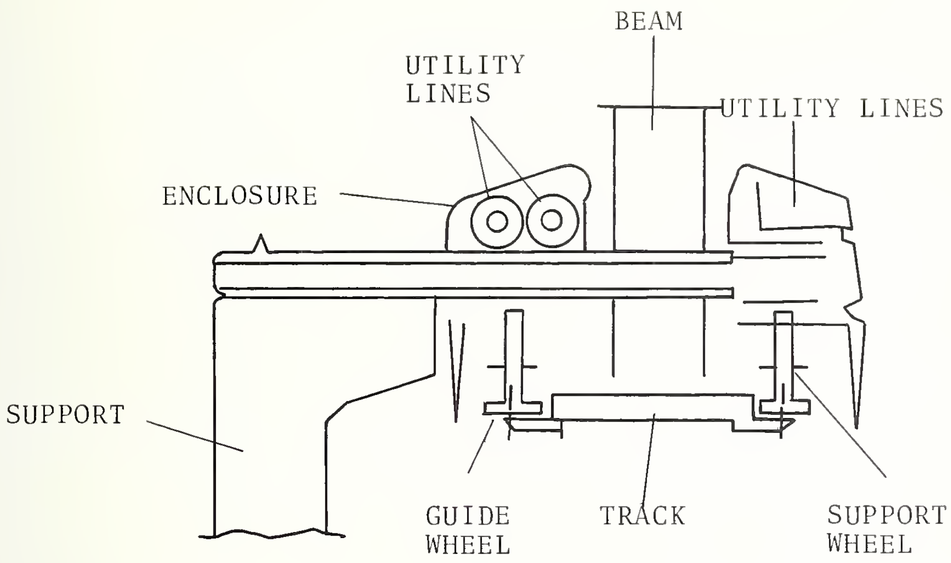


Figure A2-7. Guideway Cross Section

Figure A2-8. Guideway with Aluminum Cover Attached

Figure A2-9. Concrete Columns Piers with Cantilevered Arms

The columns are set in cylindrical foundations also of reinforced concrete. The guideway beams, which are not prestressed are fixed at one pier with an expansion joint at the next. A special single pylon (see Figure A1-2) is used near the entrance of the main hospital to support the 39.5 m curve. The difference in height between the two stations is 2.43 m (7.97 ft). The guideway at the top-point is 4.07 m (13.5 ft) higher than station A. This elevation assists an emergency power supply in the vehicle when moving the vehicle to a downhill station in the event of a power failure.

A2.4 VEHICLE

The vehicle is of aluminum light-weight design and measures 3.80 m (12.4 ft) long, 1.96 m (6.43 ft) wide, and 2.33 m (7.7 ft) high (see Figure A2-10). The welded framework is made of aluminum-extruded sections reinforced with coffered sheet metal. There is an automatic sliding door 1.17 m (3.8 ft) wide at each end of the vehicle; large enough to accommodate a hospital bed.

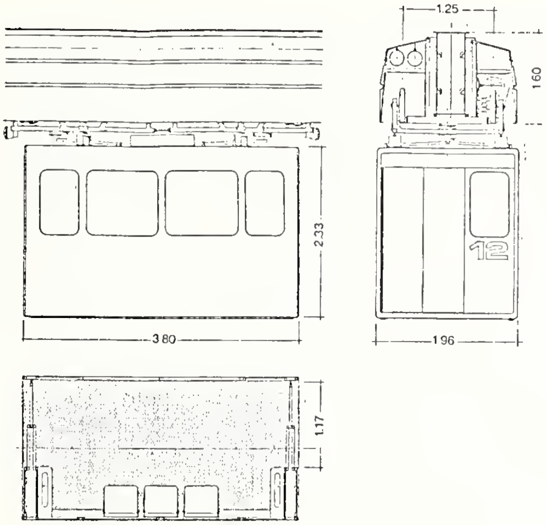


Figure A2-10. Vehicle Dimensions

Spring-loaded cushioned suspension is provided via two bogies, each of which is equipped with four load-bearing and four guilding rubber-tired wheels (Figure A2-11). All control electronics are carried on board. The vehicle is powered by two linear-induction motors (Figure A2-12) governed by the LIM controller and has six hydraulic brakes and four spring brakes in addition to two linear-induction brakes.

A heating and ventilating system which uses a temperature controlled warm air blower is incorporated in the vehicle. There is no air conditioning. The vehicle is capable of transporting 1000 kg (2200 lb), or 12 persons over the empty weight of 2200 kg (4840 lb). Normal operating speed is 6 m/s (19.68 ft/sec) and is possible under manual control.

Two 12-V, 45 amp-hr batteries are provided for emergency operation in the event of power failure, and an intercom system provides contact with the hospital switchboard. The vehicle also is furnished with hydraulic holding catches and an overload sensing device for use in the stations. (See Section A3.4 on Safety for further discussion of these features.)

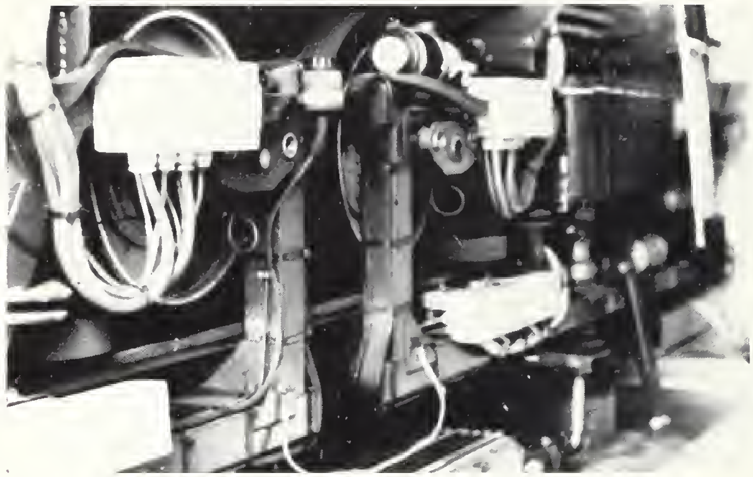


Figure A2-11. Cabinlift - Suspension and Rubber Wheels

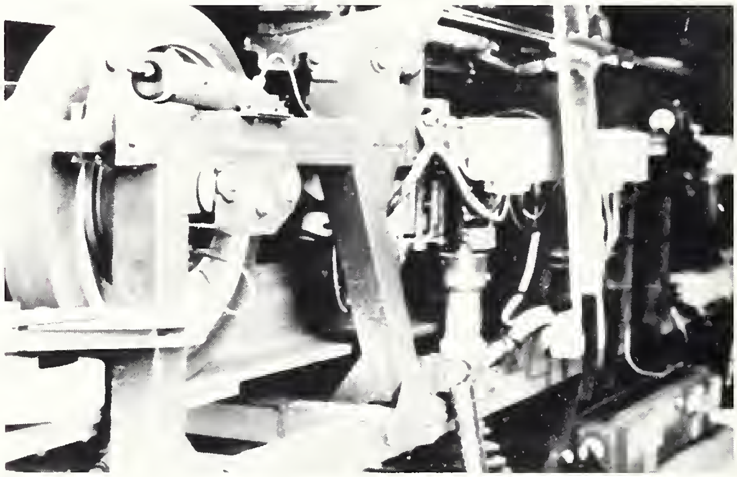


Figure A2-12. Cabinlift Linear Motors and Reaction Plates

A2.5 STATIONS

The stations are located on the second floors of the two buildings connected by the Cabinlift at the stub ends of the guideway (Figure A2-13) (see Figure A2-4 block diagram for station components). The vehicle docking area is separated from the passenger waiting area by sliding doors 1.13 m (3.7 ft) wide. The station as viewed from the passenger side is quite similar to that of an elevator, and the doors are equipped with an electric eye to protect the passengers from door closure. The electric eye is aimed at an angle in order to assure that beds passing through or standing in the doorways will be detected. Patients and goods are transported from the station into the building by elevators which are color coordinated with the Cabinlift vehicle and station, thus further enhancing the impression of the Cabinlift system as a horizontal elevator.

The station is equipped with a hydraulic safety cable brake which is engaged by a special wheel on the vehicle when entering. This cable brake provides final emergency braking if a vehicle is traveling too fast on station entry. (See Section A3.4 on Safety.)

A lowering frame sits on the floor of the station docking area to provide precise leveling with the hospital floor area, thus facilitating the movement of beds and other large cargo in and out of the vehicle. The vehicle is lowered onto the frame through hydraulic lifters located on the vehicle itself.

The station at the main hospital is large enough to accommodate a small service area which also houses the maintenance vehicle (described in the System Maintenance Section).

A2.6 OPERATIONAL SUPPORT

Electric power is distributed to the vehicle from a substation located in the main hospital. Three-phase 380-volt power is supplied to the vehicle through four hollow copper rails. Rail insultation and support is provided every 2 m (6.56 ft) by glass-reinforced polyamide units. The power rails are located within the enclosed guideway (Figure A2-14), thereby protected from the weather. Each rail section is 8 m (26.24 ft) long. Power collection performed by articulated graphite-impregnated brushes (Figure A2-15), one set at each end of the vehicle. A collector is capable of handling up to 140 amperes.

The system also includes a battery-powered service vehicle which is used for maintenance work or handling emergencies (see Section A2.7 on System Maintenance).

A2.7 SYSTEM MAINTENANCE

There are no formal maintenance buildings or facilities required at the Ziegenhain installation. A service area is provided, as part of one of the two stations, which allows convenient access to the vehicle and its control equipment. The vehicles are cleaned by hand by custodians.

The maintenance program defined for the Cabinlift system at Ziegenhain is basically similar to routine maintenance that might be expected for an elevator installation. The maintenance program is divided into weekly, monthly, quarterly, and yearly checks. All, except the yearly check, can be performed by the elevator technician responsible for the elevators at the hospital. A DEMAG technician is on call and can arrive at the site within an hour if technical problems occur. The yearly check is performed in the presence of an official from the TÜV (state elevator authority) by DEMAG since the process involves electrical testing of the propulsion controller. The maintenance procedure until January 1, 1977, has been as follows:

Figure A2-13. Vehicle Approaching Station at Out-Patient Clinic Building

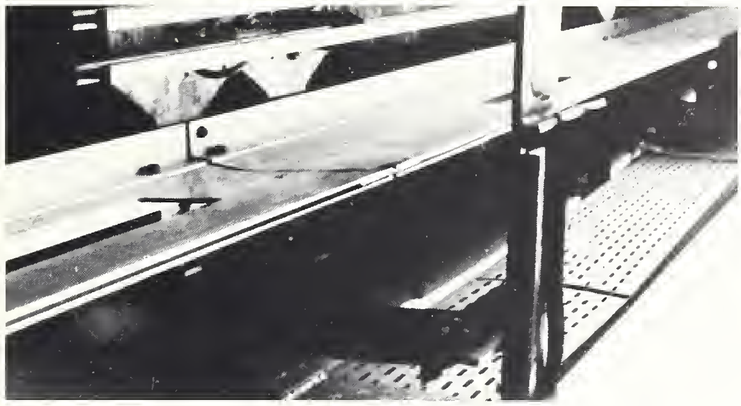


Figure A2-14. Power Rails Installed in Guideway

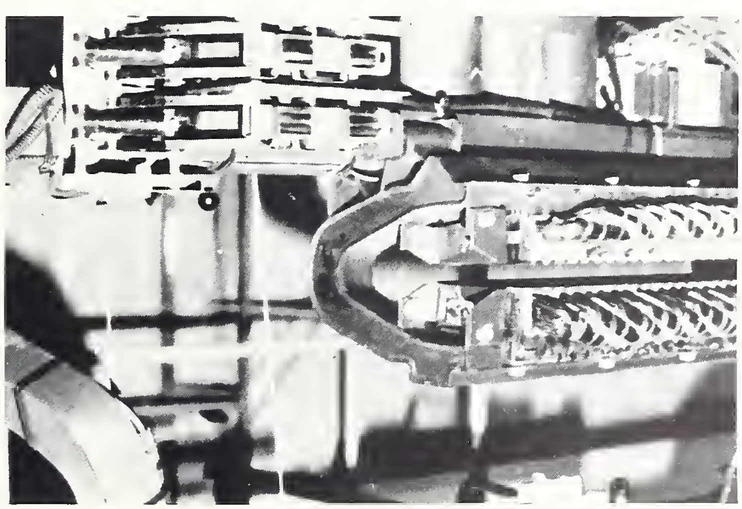


Figure A2-15. Power Collector Assembly

Weekly

(1) Visual inspection.

(2) Operation of the emergency stop button on the vehicle.

(3) Qualitative assessment of acceleration and jerk.

(4) Test drive under battery power.

(5) Check-out of the intercom system.

Monthly

(1) Check bearing and guide wheels for wear.

(2) Check battery water.

(3) Check hydraulic fluid levels.

Quarterly

(1) Door Checks and overhaul.

Yearly

(1) Check controller.

(2) Check brakes on vehicle.

(3) Check emergency cable brake at stations.

(4) Check all signals between stations.

Since January 1, 1977, the monthly maintenance has been changed to once per quarter. This preventive maintenance has been quite sufficient. However, it cannot reduce or eliminate component wear. Modular replacement is an approach, but nothing can yet be said about this after such a short period of time.

There is no automatic check-out facility in the Cabinlift system at Ziegenhain for quick detection and documentation of failures. The propulsion control has a check-out connection. Testing, however, is not automatic, and is accomplished with additional equipment. The failures which arise are recorded in a maintnenace log by the maintenance official during the routine inspections or by the hospital manager during accidental disturbances. The date, time of day, duration of failure, causes, affects, and corrective measures are recorded. (Failure history is discussed in the Section on Reliability and Availability).

The battery-powered service vehicle which runs on a separate track on top of the guideway beam (Figure A2-16) is used for maintenance work or handling of emergencies. An extension arm allows a personnel cage to hang outside of the profile of the vehicle permitting maintenance work to be done on the guideway and on the vehicle. The service vehicle can operate independently from the passenger vehicle and is steered by a driver. This equipment is also used for evacuation of the Cabinlift vehicle in the event that the vehicle stalls on the guideway (see Section A4 on Human Factors for a discussion of the evacuation procedures).

Figure A2-16. Battery Powered Service Vehicle

A3. OPERATIONAL PERFORMANCE ASSESSMENT

A3.1 SYSTEM PERFORMANCE SUMMARY

The Cabinlift shuttle system is demand-activated, and presently operates approximately 16 hr/day, 5 AM to 9 PM. The performance parameters include a cruise velocity of 6 m/s (19.68 ft/sec), an acceleration of 0.35 m/s^2 (1.14 ft/sec^2), and a jerk rate of 0.3 m/s^3 (0.98 ft/sec^3) over the 578 m (1896 ft) guideway. No operator or controller is required. Routine maintenance is performed by DEMAG technicians under contract.

Overall safety is addressed through redundant speed control circuits on the guideway, door interlock circuits within the vehicle, an overload sensing device for use in the stations, an emergency voice communication system, and special cable brake systems at the two end stations.

The vehicle is equipped with emergency batteries which provide lighting and communications as well as vehicle movement to the nearer end station in the event of a power failure. If the vehicle is to be driven to the station under battery power, the service personnel can switch the hook-up equipment to "breakdown" and drive the cabin into a station. However, the docking and lowering of the vehicle will not take place. The doors can then be opened by hand, allowing the passengers to disembark.

The system is also equipped with a special battery-powered recovery vehicle which can operate on top of the guideway and either remove passengers or carry maintenance personnel to repair a malfunction.

The vehicle is capable of negotiating grades up to 10 percent, although the grade at the present installation is only 3.4 percent.

The system is capable of nearly 17 one way trips per hour giving an effective hourly capacity of about 200 passengers (vehicle capacity equals 12 passengers). Capacity however, was not one of the design requirements. The prime performance measures to which the system was designed, developed, and tested are the jerk and acceleration rates. These were selected to accommodate patients with infirmities, delicate medical equipment, and the movement of food, especially soup in open bowls between the two buildings.

Emergency braking for the vehicle is 1.0 m/s^2 (3.28 ft/sec^2) loaded with 1000 kg and 1.5 m/s^2 (4.92 ft/sec^2) unloaded. Operation in inclement weather with minimum degradation is possible because the vehicle is suspended below the guideway which is protected from the weather by a shield. To date, no operational problems have occurred due to inclement weather.

A3.2 OPERATIONAL EXPERIENCE

During the Ziegenhain system design phase, the trip frequency of the Cabinlift was estimated to be 50 trips per day per direction. After it was put into service, as many as 100 trips per day per direction were made. About 11,180 trips (580 m/trip) were recorded from August 31, 1976 to January 18, 1977, after the installation of a counting device. This corresponds to an operational performance of about 6500 vehicle-kilometers (4025 vehicle miles) during this time period, or an average of 46 vehicle kilometers per day (approximately 40 round trips per day). It is projected that the Cabinlift will travel 17,300 vehicle-kilometers per year.

Although the shuttle vehicle is operational and available for service from 05:00 to 21:00 hours, the actual usage time is limited to 11 hours from 07:00 to 18:00 hours. The average time required for round trip including halt times at the stations is about 10 minutes. Using a figure of 50 round trips per working day, it can be seen that the Cabinlift is in use about 76 percent of the day, computed as follows:

$$\frac{\text{50 round trips per day X 10 minutes per round trip}}{\text{11 hours per day X 60 minutes per hour}} = 0.76$$

This percentage includes the travel times for the empty cabins when ordered to a station.

Experience to date with items such as power pick-up brushes and load bearing, and guide wheels indicates a wear-out rate consistent with that expected by DEMAG. Power pick-ups have to be changed about every 150 days, representing approximately 9000 km (5400 mi) of running. Load bearing wheels are expected to have to be replaced at about 50,000 km (30,000 mi), and guide wheels at about 25,000 km (15,000 mi). The system can tolerate about 5 mm (0.2 in) of bearing-wheel wear before replacement is required.

The test program and early operational data have shown that no items have required a redesign. However, some items are candidates for improvement. The linear induction motor (LIM) used for Cabinlift was potted (encapsulated in plastic) around the motor windings. This caused some heat dissipation problems during the early test phase. However, the Ziegenhain LIM was not changed since the heating effect was considered minor. The motors operate nominally on 380 volt, 3-phase ac and can maintain operation including propulsion and braking with a maximum of 15 percent loss of this nominal voltage without adverse effects in the system operation.

The control enclosure for electronics within the passenger cabin is too small to accommodate all the electronics without crowding; subsequent designs will address this problem. The guideway has required no adjustments since installation and the basic guideway design will remain unchanged; however, there will be a few construction details modified. A new girder covering developed since the Ziegenhain installation is expected to result in less expensive installation and more efficient noise absorption.

One item that has been redesigned for future installations, as a result of Ziegenhain testing, is the self-powered maintenance and rescue vehicle. Motion along the guideway was quite rough because of its single drive wheel, causing significant swinging of the personnel cage. In addition, the support structure of the cage was rigid, thus preventing level platform orientation on grades. A new vehicle has been designed to solve these problems and was undergoing tests at Hagen during October 1976. Dual-powered drive wheels have been installed and a pivot has been added to allow the cage to swing level on grades.

The Ziegenhain Cabinlift vehicle is heated and ventilated. Space for an air-conditioner is available between the bogie and the cabin top; however, no installation is being considered at this time. An investigation was conducted during the design phase to select a unit, but all air-conditioners meeting the requirements for the system proved to be too noisy.

A3.3 RELIABILITY AND AVAILABILITY

For the Ziegenhain Cabinlift shuttle vehicle system, close to one year of practical operational experience has been accumulated up to the beginning of 1977. It is possible, therefore, to provide an assessment of the reliability

and the availability of the system. However, care should be exercised in relating the conclusions drawn here to the Cabintaxi/Cabinlift system since the Ziegenhain Cabinlift has been designed for special requirements and circumstances in the hospital environment and its design deviates from the latter in several areas; for example, the auxiliary propulsion on the vehicle with extra loading apparatus, the equipment for lowering and raising cabins in the stations, and the overall system control.

A3.3.1 Definitions

Many definitions and descriptions of reliability can be found in the literature [1,2,3]. This subject has been covered in more detail in the main report. For the purpose of this analysis, reliability R(t) is defined as the probability that within a given time interval (o,t), no malfunction in the total system or in the subsystem being considered, will occur. The failure rate r(t) is defined as the number of failures per unit time at t. It is well known that R(t) satisfies the differential equation.

$$\frac{dR(t)}{dt} = -r(t)\,R(t) \qquad R(0) = 1$$

In order to draw a comparison with other automatic systems, the concept of Mean Time Between Failure (MTBF) will also be used. MTGB is defined theoretically as:

$$MTBF = -\int_{o}^{oo} t\,\frac{dR(t)}{dt}\,dT$$

and in practice can be obtained as follows:

$$MTBF = \frac{B}{N} = \frac{1}{N}\sum_{(2)}^{N} t_i$$

where:

B = Total operational time in which the system has operated without malfunction. It is not to be confused with planned daily usage.

N = Number of registered malfunctions [4].

t_i = Time interval between completion of malfunction report after the system failure i-1 and the beginning of the system failure i.

This is illustrated in Figure A3-1.

A common practice is to assume a constant failure rate. In which case, the failure rate becomes the reciprocal of the MTBF. (See References 5, 6 and and 7 for further discussion of reliability.)

A3.3.2 Detection of Malfunctions

The shuttle vehicle has no automatic checkout facility for quick failure recognition and failure documentation. Malfunctions are documented by a qualified maintenance worker during regular inspections, and change or casual malfunctions are handled by personnel responsible for the shuttle within the hospital. In this way the date, time of day, time which the malfunction was in effect, cause of the malfunction and effect of the malfunction and/or the measures which were taken to correct it are documented.

Malfunction analysis must distinguish between

- Failures which are caused by inappropriate or improper use of the system, and
- Malfunctions which are dependent on the system.

The first group of malfunctions are caused by intentional or unintentional actions by the user. Examples of these are:

- overloading of the cabin
- blocking the door by interrupting the electric eye
- disposing of cigarettes or butts in the door closing tracks
- improper use
- inattentive loading of containers and bed which cause damage to the doors

With regard to system caused malfunctions, differentiation must be made between functions which occur after a short time in operation (infant mortality

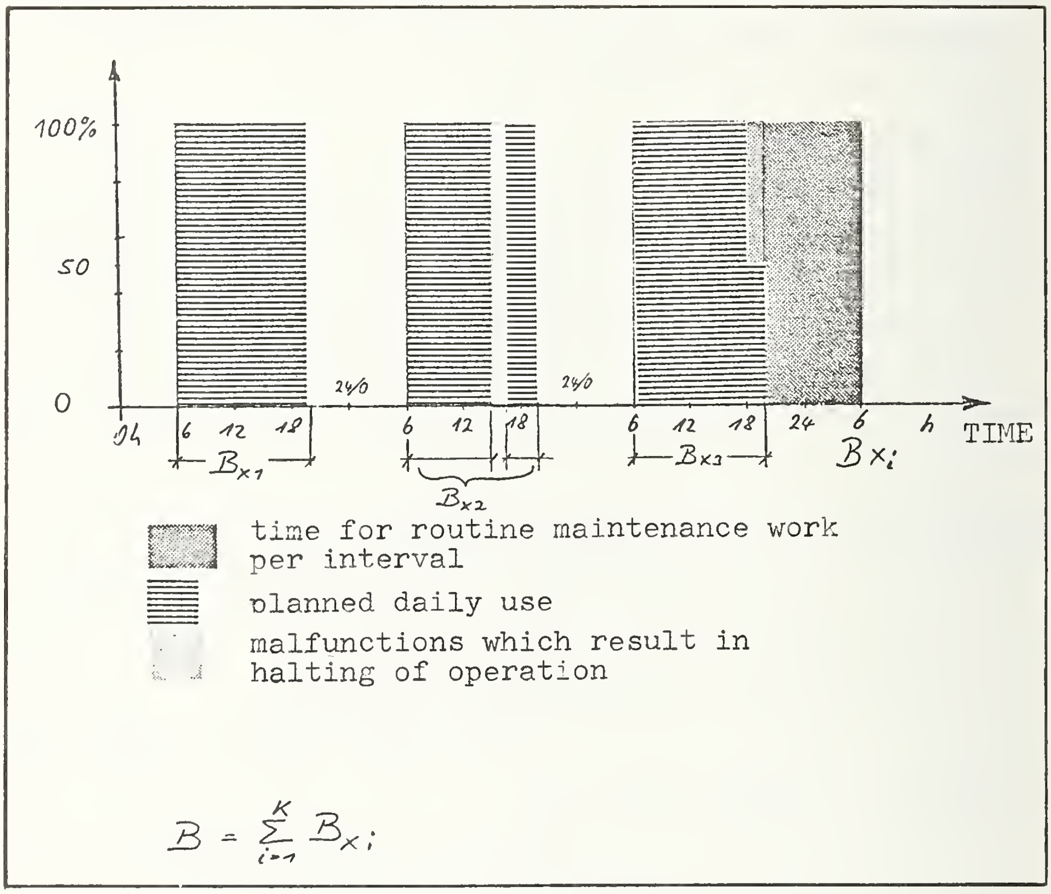


Figure A3-1. Example Illustrating the Concept of Reliability and MTBF

associated with the deployment of any new system), and the actual malfunctions which occur during the main useful life of the system. The number of these types of malfunctions can, in general, be held to a low level by appropriate maintenance.

Since the system has been in operation only a short time, nothing definite can be said with regard to the wear on system components that cannot be corrected by preventive maintenance.

During the interval from August 1, 1976 to February 18, 1977, eight malfunctions occurred in the total system (Table A3-1). These were classified into the following four categories:

1. Failures which could, but not necessarily lead to accidents.
2. Serious disturbances to operations; failures which could cause portions of the track or stations to be blocked off fall into this category.
3. Less serious disturbances to operations; in these cases, the vehicle speed might be diminished.
4. These are failures which have no direct effect on operations or safety, and which can be taken care of at the time of the next maintenance check.

A3.3.3 Results

Based on the actual failure data given in Table A3-1, the MTBF and the Mean Time to Restore (MTTR) can be computed as follows:

$$\text{MTBF} = \frac{\text{Total Operational Time}}{\text{Number of Malfunctions}}$$

$$= \frac{\text{Planned usage time per day x number of days} - \text{malfunction time interval}}{\text{Number of failures}}$$

$$= \frac{14 \times 202 - 35.75}{8} = \underline{349 \text{ hours}}$$

Table A3-1

ZIEGENHAIN CABINLIFT SYSTEM FAILURE HISTORY(8/1/76 to 2/18/77)[1]

Date	Failure Type Category	Cause	Disturbance Duration	Remarks
9/8/76	system-specific failure Category B	defective pressure switch in hydraulic pump	14 h	
9/18	system-specific failure Category C	failure of eddy current brake	16 h	
9/27	system-specific failure Category D	safety catch does not function properly	0	(3)
10/6	system-specific failure Category D	defective cable connection	0	(3)
10/16	behavior failure - disturbance in station control	damage to door dirt in door slit	0,75 h	
11/23	system-specific failure Category C	defective cable	2 h	
1/18	system-specific failure Category D	safety catch does not function properly	0	(3)
1/29	system-specific failure Category B	defective end switch in weighing device	3 h	
N = 8			35.75	

Notes: (1) without "early life failures": 3 failures with 15 h disturbance duration,
(2) duration of time from onset of malfunction to repair completion and return to operation in hours,
(3) were eliminated or repaired during periodic inspection

$$\text{MTTR} = \frac{\text{Total length of time malfunction was in effect including repair time}}{\text{Number of malfunctions}}$$

$$= \frac{35.75}{8} = \underline{4.46 \text{ h}}$$

Using the conventional definition of availability, the computed availability is:

$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \qquad \frac{349}{349 + 4.46} = 0.9873 \text{ or } 98.73\%$$

User caused operational malfunctions were also recorded. It was found that they were very small as compared to the total malfunction time.

Since only one operational vehicle is used in this system, the availability is effected strongly by the repair time, which is identical to the down time of the system. In larger facilities with several vehicles, a malfunctioning vehicle can be quickly removed and operation can continue with the remaining vehicles. In this case, the computation of availability is much more involved. Definition of availability for the user will be different from that for the operator.

A3.4 SYSTEM SAFETY

During the early planning stages, several types of possible failures were studied, and suitable installations and measures were worked out to minimize or prevent their possible effects.

The following safety-related conditions were considered in the design of the Ziegenhain Cabinlift system:

1. Prevention of a vehicle collision with the station wall caused by brake failure.

   Vehicle deceleration near the station is triggered by two magnetic indicators positioned in the guideway so that the LIM controller decelerates the vehicle safely and comfortably from the maximum speed to the station speed. For in-service braking

the vehicle is equipped with two brake systems: electric linear brakes and hydraulic wheel brakes.

About halfway along the braking path into the station, the speed is monitored by equipment fixed to the track guideway. If the speed is too high, the current will be switched off. The vehicle makes an emergency stop using the spring mounted brakes and comes to a stop in front of the catches in the station. The safety catches in the station are only used in case of failures of both the hydraulic wheel brakes, and the linear induction brakes.

The velocity for the last 7 m (25 ft) before entering a station is 0.3 m/s (0.98 ft/sec). At the 5 m (16 ft) point, the vehicle engages the safety cable, unwinding it from a rotating brake drum as the vehicle approaches the station. The safety cable brake was designed specifically for the Ziegenhain system and offers little resistance if the vehicle enters the station at the normal acceptable speed. At greater than normal speeds, the emergency cable brake will slow the vehicle at a rate of 3.0 m/s^2 (9.84 ft/sec^2). Before a vehicle is released from one station, a signal must be present indicating the status of the emergency cable brake at the other station. Should this signal not be present because of a malfunction in the cable system, the vehicle will not be allowed to leave the station.

Control of the LIM at low speeds is difficult due to system tolerances which become a larger percentage of the control signal at low power levels. Shock absorbers at the station force the motor to use higher power levels during docking with the result that the stopping sequence at the station is quite smooth. A mechanical latch attaches the vehicle to the wall, power is removed, and hydraulic lifters lower the vehicle onto a skid (lowering frame) that provides proper alignment between the hospital floor and the vehicle floor.

Should difficulties be encountered enroute, there is a switch above the door in the vehicle for emergencies. When pulled, it initiates emergency braking. Thereafter, the main current is shut off and emergency power is used to move the vehicle into the nearest station.

2. Auxiliary drive for the vehicle in the case of loss of power, so that it can reach one of the two stations on its own power, and/or accessibility to the failed vehicle on any portion of the guideway with the help of a service vehicle.

   When there is a power failure, the vehicle can reach one of the two stations at a speed of 1.0 m/s (3.27 ft/sec) on battery power. The battery is charged continuously during normal operation. If the auxiliary drive fails, for example, due to a short-circuit in the electrical installations, the service vehicle will be called. It runs on the upper surface of the guideway and can reach any position to recover people from the cabin (see Section A4 on Human Factors for discussion of evacuation).

3. Overload Conditions

   Before a trip starts, the station and cabin doors are closed simultaneously and the cabin is raised via on-board hydraulic lifters. A weight sensor is attached to these hydraulic lifters to limit the maximum load to 1000 kg (2200 lb). If this load factor is exceeded or if the load is distributed asymmetrically, the vehicle will not be lifted. If the vehicle is not lifted within an adjustable time, a horn will sound and the door will open. This cycle will continue at every attempt to leave the station until the load is reduced or properly adjusted.

4. Prevention of Vehicle Derailing

   The bogie spans the entire width of the carriers. Since the possible horizontal and vertical tolerances are smaller than the tread surface for the carrier and guide wheels, derailment is not possible.

A4. HUMAN FACTORS

A4.1 PASSENGER SAFETY

Consideration for passenger safety is evidenced throughout the Ziegenhain Cabinlift system in a number of features. The limitations placed on the control system relative to acceleration, deceleration, and jerk during vehicle travel minimizes the possibility of injury due to ride anomalies. An electric eye in the station doorway set at an angle will detect not only the presence of passengers, but also the presence of such items as a bed straddling the doorway, thus preventing injury or inconvenience due to inadvertent door closure. In addition, the door closing activating mechanism is equipped with a rotary magnet that has a limited activation force precluding injury of persons.

The vehicle itself contains safety glass and hand-holds, and the lowering frame in the station permits exact alignment of the vehicle floor with the hospital floor permitting safe access and egress. An overloaded or unbalanced vehicle which could lead to passenger injury during travel is prevented through the vehicle weighing system.

A4.1.1 Fire Safety

The Cabinlift system in the Ziegenhain Hospital must adhere to high standards of fire safety because of the elevated guideway and the automatic operation of the system. The system is certified according to the guidelines for elevator systems and must, therefore, meet the safety requirements for elevators with respect to fire safety.

Since the system, for the most part, incorporates concepts and components of the Cabintaxi, the fire safety standards described in the main part of the study, as well as fire safety materials, etc., were also used in the Ziegenhain Hospital system. The interior components (e.g., seats, interior coverings and hand grips) are made of difficult to ignite, self-extinguishing material. There is no heat shield between the cabin and the bogie. The use of a hanging car has an advantageous effect with respect to fire safety. The bogie, including the electrical components for propulsion and braking (LIM, LIB, etc.) are located above the cabin, so that there is reduced risk of fire which originates in the bogie reaching the passenger cabin.

In case of an emergency, the vehicle is equipped with an intercom system and supplementary drive batteries; furthermore, a maintenance/rescue cage can be put into service.

The transit time of the Cabinlift between the stations, approximately 3.5 minutes, is relatively long. Smoke developed by a fire within the cabin or within the control unit, or smoke which enters the cabin from the outside, could suffocate passengers before they reach the next station. The stations are equipped with fire extinguishers, however, the vehicles are not.

Experimental results pertaining to the development of smoke, as well as the toxicity of gases developed in fires which may occur aboard the Cabintaxi, can be expected from planned fire tests. These results should be considered as they may apply to the Ziegenhain system. Suitably adapted fire-fighting equipment should be installed in the individual cars for fire-fighting purposes.

A4.1.2 Evacuation Procedures

The service vehicle can be used to evacuate passengers stranded in a vehicle stalled on the guideway. The vehicle operates on a separate rail located on top of the guideway permitting the driver to position it adjacent to the stranded vehicle. Figures A4-1 through A4-5 depict an evacuation sequence for a bed-ridden patient.

In Figure A4-1 the personnel cage of the service vehicle is positioned next to the end of the Cabinlift vehicle. A platform is lowered from the personnel cage in Figure A4-2 providing access from the doors situated at the end of the Cabinlift vehicle. Figure A4-3 shows the setup of a protective barrier around the periphery of the platform. In Figure A4-4 the patient's bed is rolled from the Cabinlift vehicle onto the service-vehicle platform. Figure A4-5 shows the service vehicle moving away from the stalled vehicle with the bed-ridden patient and attendent.

A4.2 PROVISIONS FOR HANDICAPPED

Since the Cabinlift system at Ziegenhain is installed on a hospital complex, provision for the handicapped is inherent in the design. The entire system is barrier free. Access to the station is provided via elevators, and the

Figure A4-1. Service Vehicle Approaching Stalled Cabin

Figure A4-2. Evacuation Platform Lowered From Service Vehicle

Figure A4-3. Protective Barrier on Service Vehicle Platform

Figure A4-4. Patient Being Moved from Cabin to Service Vehicle

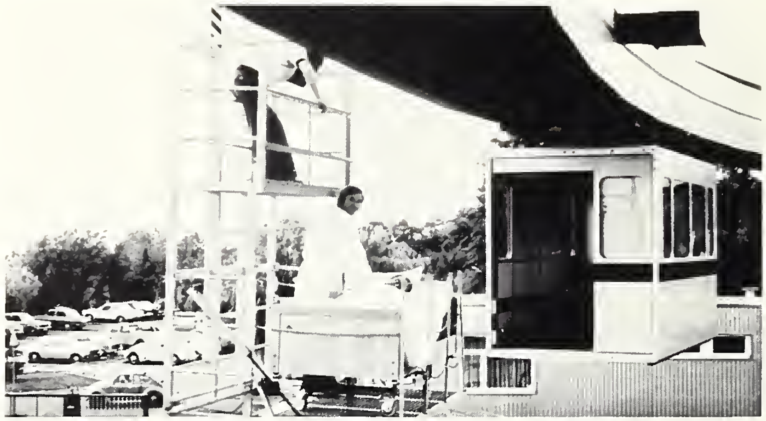


Figure A4-5. Service Vehicle Carrying Patient to Station

vehicle floor is closely aligned with the hospital floor. Grab-rails are strategically placed and the vehicle contains seats along the walls to accommodate patients.

A4.3 RIDE QUALITY

The acceleration and deceleration of the vehicle are very smooth with no apparent jerk. The overall ride quality for a critical observer is bumpy with a sharp lateral jerk. The lateral jerk occurs at one girder at the pylon construction. At that girder the standard guideway design had to be changed due to static requirements. No measurements of the physical attributes of the ride quality were available at the time of the visit. They will be made in the future. An analog recording of the vibration in one dimension, viewed at MBB, confirmed the existence of the periodic bumps.

The bumps were attributed to the discontinuity of the guideway at the supporting columns. This is due to the fact that the beams are simply supported on the columns. The manufacturer notes that the accuracy of the lane of Ziegenhain track could be improved as a result of tests, development, and more accurate prefabrication and assembly of the guideway.

A5. ENVIRONMENTAL CONSIDERATIONS

A5.1 AESTHETICS

The guideway and stations are architectually attractive. The slender columns and narrow guideway are visually pleasing as the system traverses a forest clearing close to tree-top heights. The guideway curves over a building to the station at the main hospital building. Since the system is on private hospital property, not in an urban area, the public acceptance of a large scale elevated system is not an issue.

The vehicle is also very attractive. The exterior color of the vehicle is totally integrated with the colors of the guideway and the hospital buildings. The interior design and the interior color of the vehicle matches that of the elevators in the stations.

A5.2 NOISE

Subjectively, the rubber wheels and the linear-induction motor make the ambient noise in the vehicle almost imperceptible. Measurements of the Ziegenhain Cabinlift made by an independent noise consultant show interior levels between 59 and 65 dB (A), mean noise levels. Noise measurements were also made along the guideway. Maximum levels at certain spots of the guideway reach higher levels up to 70 and maximum 75 dB (A), but the mass of measurements are at the 59 to 65 dB (A) range. Measurements were also made in the station and in a hospital room near station A. The noise in the station during approach and departure was between 45 and 55 dB (A), and in the hospital room was between 43 and 47 dB (A) [8]. According to the noise consultant the above levels can be further reduced if the flow of bodyborne sound between bogie and cabin is reduced.

The noise created by docking in the station is not at all disturbing. In addition to the steady-state docking noise, short noise peaks were created in the room during the docking procedure (about 59 dB (A)) and in the station halls during the opening and closing of the door (about 65 - 70 dB (A)) (defective door stop).

A5.3 POLLUTION

The electrically-powered vehicle does not contribute to air pollution directly. There is also negligible pollution contribution from the main power generation facility supplying the electrical power requirements of the system.

A5.4 ENERGY

Based on previous measurements, the average energy consumption for a 12 seat cabin on the 578 m (1897 ft) trip is 0.68 kWh. This is equivalent to 1.17 kWh per vehicle kilometer or 1.87 kWh per vehicle mile.

A5.5 LAND AND SPACE REQUIREMENTS

The dimensions of the foundation plates are 4.8 m x 3.3 m (16 ft x 11 ft). The vertical standing supports are between 6.73 m (22 ft) and 17.73 m (58 ft) high. The guideway presents no obstacle to pedestrians, and for the most part, no obstacle to vehicles traveling beneath it.

The supports above the foundations have cross sections between 0.79 m x 0.6 m (2.5 ft x 2 ft) and 1.25 m x 0.8 m (4.1 ft x 2.6 ft). They are thinner at the top than at the bottom. The distance between the supports, in general, is 28 m (92 ft) and near the terminals about 41 m (135 ft). The overall dimensions of the guideway and vehicles are shown in Figure A5-1.

The stations are completely integrated into the hospital buildings. As a whole, the system offers an efficient use of space.

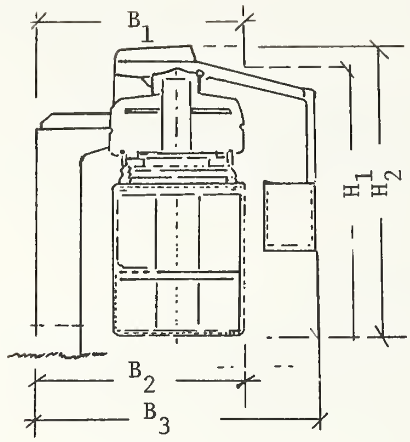


Figure A5-1. Overall Dimensions for Cabinlift

A6. SYSTEM COST

A6.1 CAPITAL REQUIREMENTS

The contractual agreed fixed price for the system was 1.852 million DM. With value added tax, it came to 2.056 million DM (U.S. $822,400). The system was delivered for 2.25 million DM. The capital requirements for the individual components, including delivery and assembly, is presented below.

	Number	Price per Unit		Capital requirement in thousands DM (TDM)
Guideway	578.2 m	2,829 DM/m		1,630.52
Pick up point	2	200 TDM/piece		400.--
Vehicle	1	200 TDM/piece		200.--
Service vehicle	1	20 TDM/piece		20.--
			Total	2,250.52

A6.2 INVESTMENT COSTS

Using the useful life given for the system in Section 7 (main part of the study), one arrives at a per-year investment cost as follows, with the interest rate at 6%:

	Useful life (yrs)	Annuition factor	Capital require-ments in TDM	Investment costs in TDM per year
Guideways	50	0.0634	1,630.52	103.37
Pick up points	50	0.0634	400.--	25.36
Vehicles	10	0.1359	200.--	27.18
Service vehicle	10	0.1359	20.--	2.72
		Total	2,250.52	158.63

A6.3 OPERATIONAL COSTS

The Cabinlift in Ziegenhain was put into operation in March 1976 and was completely integrated into the hospital operation in July 1976. The operational costs for the time from July to December 1976 were used to project the operational costs which would have been encountered in a year. Linear extrapolation is used.

Since the time interval considered here was shortly after the beginning of the deployment of the system, some of the starting-up problems of the system are also reflected in the total costs. However, these problems have been to a large extent solved. The additional costs encountered due to these starting-up problems are shown separately. It should be noted that the information presented here can be considered as valid only for the start-up phase of operation. Generalization to long-term operations needs to be further validated.

A6.3.1 Personnel and Material

During the first six months of operation, maintenance was carried out monthly. In normal operations, maintenance is only required quarterly. The cost per maintenance was 500 DM (wages and material). The repairs were done by personnel from the manufacturer under guarantee. The time distribution of the repairs was that 60% (or 4200 DM) occurred during the first three months due to early-life malfunctions. The additional 40% (or 2800 DM) was distributed evenly throughout the six months (467 DM/month). The hospital custodian was responsible for making repairs to minor failures such as blown fuses, and the changing of light bulbs. The time required averaged out to 1/2 hour per day at a cost of 236 DM per month. The costs for interior and exterior cleaning of the vehicle was approximately 170 DM per month. This includes the daily cleaning of the floor and wall surfaces, windows and exterior surfaces as well as application of disinfectant.

A.6.3.2 Energy

According to the measurements made up to this time, the mean energy use for the 12-place cabin for a 578 m (1897 ft) journey is 0.68 kWh. At a price of 0.13 DM/kWh and assuming 0.2490 per trip, per direction, per month (1440 vehicle-km per month) the energy costs per month were in the order of DM 216 for the vehicle. The energy use for the station was about 2.50 DM per month.

Table A6-1

ANNUAL OPERATING COST

To summarize, the operating cost per year can be broken down as follows:

Labor & Material	Annual Operating Costs
Routine Maintenance	DM 2000
Repair	DM 5600
Minor Services	DM 2832
Interior & Exterior Cleaning	DM 2040
Energy	
Vehicles (assume 1440 vehicle km per month)	DM 2594
Stations	DM 29
Total	DM 15095

The total number of trips from August 31, 1976 to January 18, 1977 (or a period of 4 1/2 months) was given in Section A3.2 as 11,180 trips. Extrapolating this over a full year gives 29,810 trips per year, or equivalently 17,300 vehicle-kilometers (or 207,600 seat km for the 12 seat cabin). Using the investment and operating cost given above, it is seen that:

Table A6-2

COST PER VEHICLE-KILOMETER

	Per vehicle - (km)
Operating costs	DM 0.87
Investment costs	DM 9.17
Total	DM 10.04
	Per seat - (km)
Operating costs	DM 0.07
Investment costs	DM 0.76
Total	DM 0.83

A6.4 CONSIDERATION OF THE STARTING-UP PROBLEM

The operational costs which were used to correct start-up problems were mainly in the areas of maintenance and repair.

Maintenance	-	Monthly maintenance at 500 DM/month to December, 1976 instead of done quarterly.
Repair	-	4200 DM for wages and material for the first 3 months of the period, from July to the end of December, 1976.

If these actual costs were used in the calculation for the first operational year, then:

● Operational	
- Maintenance	
6 months at once/quarter	DM 1000
6 months at once/month	DM 3000
- Repair	
3 months at DM 1400/month	DM 4200
9 months at DM 467/month	DM 5604
- Cleaning (same as before)	DM 2040
- Minor Services (same as before)	DM 2832
- Energy (same as before)	DM 2623
Total	DM21299
● Investment cost (same as before)	DM158630
Total	DM179929

Using these figures, it can be seen that:

	Per vehicle-km	Per seat-km
Operating costs	DM 1.07	DM 0.09
Investment costs	DM 9.17	DM 0.76
Total	DM 10.24	DM 0.85

A7. IMPLEMENTATION EXPERIENCE (CERTIFICATION PROCEDURE)

Since at that time there were no valid guidelines for the certification of private form of transport systems (NTS) having fully automatic operation, the Cabinlift was certified using existing statutory guidelines which were originally laid down for other types of systems. As a passenger carrying operation, the Cabinlift in Ziegenhain represents the first step towards the utilization of this new technology. Specifically, the two important characteristics pertain to the certification of the Ziegenhain Cabinlift system are: 1) it is a private form of transport, not a public one; and 2) the guideway does not cross any public thoroughfares.

On January 17, 1975, a conference took place with representatives of the local authorities. It was suggested that the ordinances [9] which apply to public elevators be used as a basis for granting permission to the use of the Cabinlift system. In the sense of the ordinance, elevators are defined as devices oriented toward people or stations and the things to be transported between stations, or toward the transport of freight between fixed points. They are also devices that:

- move on a perpendicular guideway or on one tilted to the horizontal, and
- are guided at least part way.

Clearly, the ordinance covers the situation of two definite stations with one appropriate horizontal guideway as well as guidance for the cabin. Hence, the name "Cabinlift" or "horizontal elevator" was used for this system.

Permission to build the guideway through the wooded lot had been previously secured from the out-patient clinic in anticipation of certification.

According to the applicable elevator ordinance, a building permit was required from the county board building department. After completion of the facility, the acceptance test had to be monitored by the appropriate personnel from the TUV.

Recovery of passengers from a stalled Cabinlift vehicle differs from that in elevator systems. A recovery vehicle similar to those seen in cable-car operations is used here. The issues which remained open or questionable after application of this ordinance were to be covered by individual decisions from the responsible authorities. The BO Strab [10] and BO Seil [11] were utilized as guidelines.

To protect against the possibility of passengers falling from the Cabinlift, the normal activation of doors and door locks were used. In fact, the operation and the use of the system by passengers were to be accomplished in the same manner as with the elevator. For example, this similarity even applies to the emergency call connection to the guard or gate keeper.

The system was designed, built, and made operable in a period of nine months. It was put into operation with a minimum of on-site testing required due to the component testing performed at the test track in Hagen. The construction of the guideway was accomplished in three months, including two months for pouring and curing of the footings. As many as five columns can be lifted onto prepared footings and aligned in a single day. The guideway beams can then be set into position and a coarse alignment made. Thus, 150 m (492 ft) of can be erected in a two day period. A third day is required to perform a finer alignment of each of the guideway segments.

Acceptance testing for the system consisted of verifying that the vehicle could transport soup in open bowls between the two buildings without spillage, and meet the safety standards and testing imposed by the elevator authorities.

A8. TECHNICAL FINDINGS AND CONCLUSIONS

The following are technical findings relative to the design, development, testing, implementation, and operation of the Cabinlift system.

The guideway is quite narrow and aesthetically pleasing, which increases the possibility of community acceptability. The small cross section is permitted by the light weight of the vehicle.

The guideway is modularized and prefabricated to minimize installation time. Prefabricated guideway sections have all elements in place, including the secondary reaction rail. In this manner, better control over alignment is maintained; all that is required during erection is alignment from one beam to the next. Column supports are also prefabricated.

The 578 m (1896 ft) Ziegenhain Cabinlift guideway was completed in three months. Two months of this were required to prepare the footings. The third month was used to erect the column supports and guideway beams and properly align the guideway segments.

A sound approach was used in the development of hardware wherein specifications and test procedures were established for components whether fabricated in-house or purchased. Each component was tested against these specifications, resulting in some redesign and improvements.

The Hagen test track was very useful in the development of the Cabinlift system. The approach employed was to make the system work as well as possible and carefully introduce refinements. Improvements in suspension, vehicle design, and control were implemented. The test track permitted the comparison of one technique with another and the direct measurement of the performance benefits.

The relatively short construction time and small amount of testing required for operational readiness of the Cabinlift system at Ziegenhain Hospital was the result of having fully developed and tested the system components and installation techniques at Hagen.

The Ziegenhain Cabinlift system, a single-vehicle shuttle system with no switching and a simple control system, operates as a horizontal elevator and as such obtained certification through the Elevator Regulatory Board.

Protection against fire is accomplished by the use of fire-proof materials. Aside from the fire extinguishers at the stations, additional fire safety should be considered, such as, rapid emergency egress, usable by all passengers including handicapped, an active fire control system in the vehicle without any harmful effects to the passengers. In addition, the result of fire tests planned for the Cabintaxi should be considered, including those pertaining to stringent specifications for the fire safety of materials.

The time interval between the closing of the cabin door and the actual departure of the vehicle is about 80 seconds. The approach to the station takes somewhat less time. For other Cabinlift facilities (such as Bremen), this preparation time should be reduced.

Unauthorized use of the Cabinlift by hospital patients has occurred. This will be avoided in the future by the introduction of the magnetic card system.

The Ziegenhain Cabinlift system has thus far demonstrated the operational safety of a single-vehicle shuttle system. Extrapolation of the Ziegenhain system to a multi-vehicle or more complex loop or network configuration would require provision of a collision avoidance scheme which is not necessary in this case of single vehicle operation.

The system as installed at the Ziegenhain Hospital is considered for the handicapped, aesthetically and architecturally pleasing, very quiet, has a relatively smooth ride, and is land-use and energy efficient. Maintenance procedures are relatively simple and the system, thus far, has been quite reliable.

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